Fishery Data Series No. 91-63

Stock Assessment of the Northern Pike Populations in Volkmar, George, and T Lakes, 1990 and 1991, and a Historical Review of Research Conducted Since 1985

by

Gary A. Pearse

November 1991

Alaska Department of Fish and Game

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ABSTRACT

Populations of northern pike *Esox lucius* in Volkmar, George and T lakes in interior Alaska were studied during spawning in the spring of 1990 and 1991. The abundance of northern pike over 299 millimeters in these three lakes was estimated in May 1990 and 1991. Based upon a two-season sampling experiment, abundance was estimated to have been 1,330 fish in Volkmar Lake in 1989 (standard error = 240; 4.9 fish per hectare). The estimated abundance of northern pike in 1990 increased to 4,038 fish (standard error = 714; 14.8 fish per hectare). In 1991, abundance was estimated to have been 4,510 (standard error = 541; 16.5 fish per hectare). Abundance of northern pike in George Lake in 1990 was estimated at 11,568 fish (standard error = 1,277; 6.3 fish per hectare) and due to sampling problems, is considered a minimum value. The abundance estimated in 1991 was 15,944 fish (standard error = 1,436; 8.7 fish per hectare). The abundance of northern pike in T Lake in 1989 was estimated to have been 298 fish (standard error = 31; 1.9 fish per hectare), based upon a two-season experiment. The estimated abundance in May of 1990 was 347 fish (standard error = 42; 2.2 fish per hectare). Abundance was estimated in 1991 to have been 328 northern pike (standard error = 54; 2.1 fish per hectare). The accurate assessment of sex composition of northern pike in all three lakes has proven difficult, and factors contributing to this problem are discussed. The length and age composition of northern pike in Volkmar Lake reflected an increased abundance of partially and fully recruited northern pike between 1989 and 1990, and again between 1990 and 1991. The length and age composition of northern pike in George Lake supports a slight decline in estimated abundance in both 1990 and 1991, compared with data available from 1987. Survival rates increased in Volkmar and T lakes, and declined in George Lake (1990), then increased (1991) for fully recruited northern pike. Between 1989 and 1991, the estimated abundance of fully recruited age 5 northern pike was statistically similar in Volkmar Lake. The abundance of age 4 fish declined in George Lake then stabilized between 1989 and 1991. The abundance of age 6 fish did not change between 1989 and 1991 in T Lake. Data collected since the inception of northern pike research in Volkmar, George, and T lakes is summarized, and a review of the northern pike program is presented.

KEY WORDS: Northern pike, *Esox lucius*, Volkmar Lake, George Lake, T Lake, abundance, sampling methods, mark-recapture, age and growth, sex composition, population dynamics.

INTRODUCTION

Background

Northern pike *Esox lucius* are popular with sport anglers in the Arctic-Yukon-Kuskokwim region (AYK), Alaska. According to current estimates of recreational fisheries harvest in the AYK region (from 1977 through the 1989 season), northern pike rank fifth for all species and fourth for indigenous stocks (Mills 1990). Harvests of northern pike in the AYK region averaged about 15,500 fish between 1977 and 1989 (ranging from 11,661 to 19,824), with more recent harvests at about 17,200 fish (Mills 1990). Anglers in the AYK region have accounted for 75% to 90% of the statewide harvest of northern pike on an annual basis, with waters of the Tanana River drainage accounting for about two-thirds of the regional harvest. Volkmar and George lakes are among the most popular fishing areas for northern pike in the Tanana River drainage, with an average of 456 fish per-year harvested in Volkmar Lake for the 9 year period from 1981 to 1989, and an average of 1,817 northern pike harvested from George Lake for the 13 year period from 1977 to 1989 (Table 1). A third lake, T Lake, has received a relatively high level of harvest (estimated at 60 fish in 1989).

Periodic distribution, stock assessment, and creel surveys of northern pike in the Tanana River drainage were conducted from 1971 to 1984 (Cheney 1972, Peckham 1972-1985). Research conducted at Volkmar Lake in 1985 (Peckham 1986) provided the first estimate of northern pike abundance and composition in Alaska. Research conducted from 1986 through 1991 has provided additional estimates of abundance, along with information on catch-per-unit of sampling effort (CPUE), catchability, sampling methods, and life history of northern pike in Volkmar, George, and T lakes (Peckham and Bernard 1987, Clark et al. 1988, Clark 1988, Clark and Gregory 1988, Timmons and Pearse 1989, Pearse 1990). This report documents research conducted in 1990 and 1991 concerning the abundance and age, sex, and length compositions of the populations of northern pike in these waters.

Study Area Descriptions

Volkmar Lake (64°07'N, 145°11'W) is a remote 273 ha (675 ac) lake located approximately 25 km northeast of the town of Delta Junction (Figure 1). The lake is accessible during the open water season by float-equipped aircraft. Snow machines and ski-equipped aircraft provide access during the winter. Volkmar Lake lies at an elevation of 326 m and has a maximum depth of 12.8 m. The lake has two small inlets and an ill-defined outlet that drains westerly through wetlands toward the Goodpaster River. Near shore waters are shallow with beds of aquatic vegetation providing spawning and rearing substrate for northern pike. Volkmar Lake is typically ice-free from mid-May to early October, and spawning activity of northern pike generally coincides with the beginning of the ice-free period and continues for up to two weeks into early June. Other fish species present include humpback whitefish *Coregonus pidschian*, least cisco *Coregonus sardinella*, and slimy sculpin *Cottus cognatus*.

Table 1. Recreational fishing effort, harvest, and exploitation of northern pike in Volkmar, George, and T lakes, 1977-1989.

Lake	Angler Days[a]	Angler Days Per Ha[a]	Harvest of Northern Pike[a]	Northern Pike Harvest Per Ha	Harvest Per Angler Day	Estimated Abundance of Northern Pike > 299 mm	Estimated Exploitation Rate if Harvested Fish were > 299 mm	Estimated Abundance of Northern Pike > 449 mm	Estimated Exploitation Rate if Harvested Fish were > 449 mm
Volkmar									
1981	458	1.7	648	2.4	1.4				
1982	546	2.0	777	2.8	1.4				
1983	270	1.0	430	1.6	1.6				
1984	436	1.6	428	1.6	1.0				
1985	711	2.6	503	1.8	0.7			4,020	0.13
1986	596	2.2	657	2.4	1.1	8,056	0.08	4,028	0.16
1987	472	1.7	224	0.8	0.5	6,932	0.03	4,230	0.05
1988	186	0.7	255	0.9	1.4	2,766	0.09	2,196	0.12
1989	466	1.7	180	0.7	0.4	1,330	0.14	1,115	0.16
Mean	460	1.7	456	1.7	1.0	4,771	0.09[b]	3,118	0.12[b]
George									
1977	854	0.5	1,227	0.7	1.4				
1978	1,271	0.7	1,392	0.8	1.1				
1979	903	0.5	2,018	1.1	2.2				
1980	1,057	0.6	1,395	0.8	1.3				
1981	1,351	0.7	2,236	1.2	1.7				
1982	989	0.5	1,635	0.9	1.7				
1983	860	0.5	1,322	0.7	1.5				
1984	557	0.3	1,700	0.9	3.1				
1985	1,127	0.6	2,670	1.5	2.4				
1986	1,957	1.1	3,076	1.7	1.6				
1987	1,467	0.8	2,229	1.2	1.5	17,662	0.13	8,495	0.26
1988	964	0.5	1,837	1.0	1.9	23,381	0.08	16,680	0.11
1989	610	0.3	882	0.5	1.4	25,466	0.03	12,606	0.07
Mean	1,074	0.6	1,817	1.0	1.7	22,170	0.08[c]	12,594	0.15[c]
T									
1989	67	0.4	60	0.4	0.9	298	0.20	271	0.22

[a] Data source: Mills 1979-1990, Mills pers comm. 1990.
[b] Includes 1986-1989 data only.
[c] Includes 1987-1989 data only.

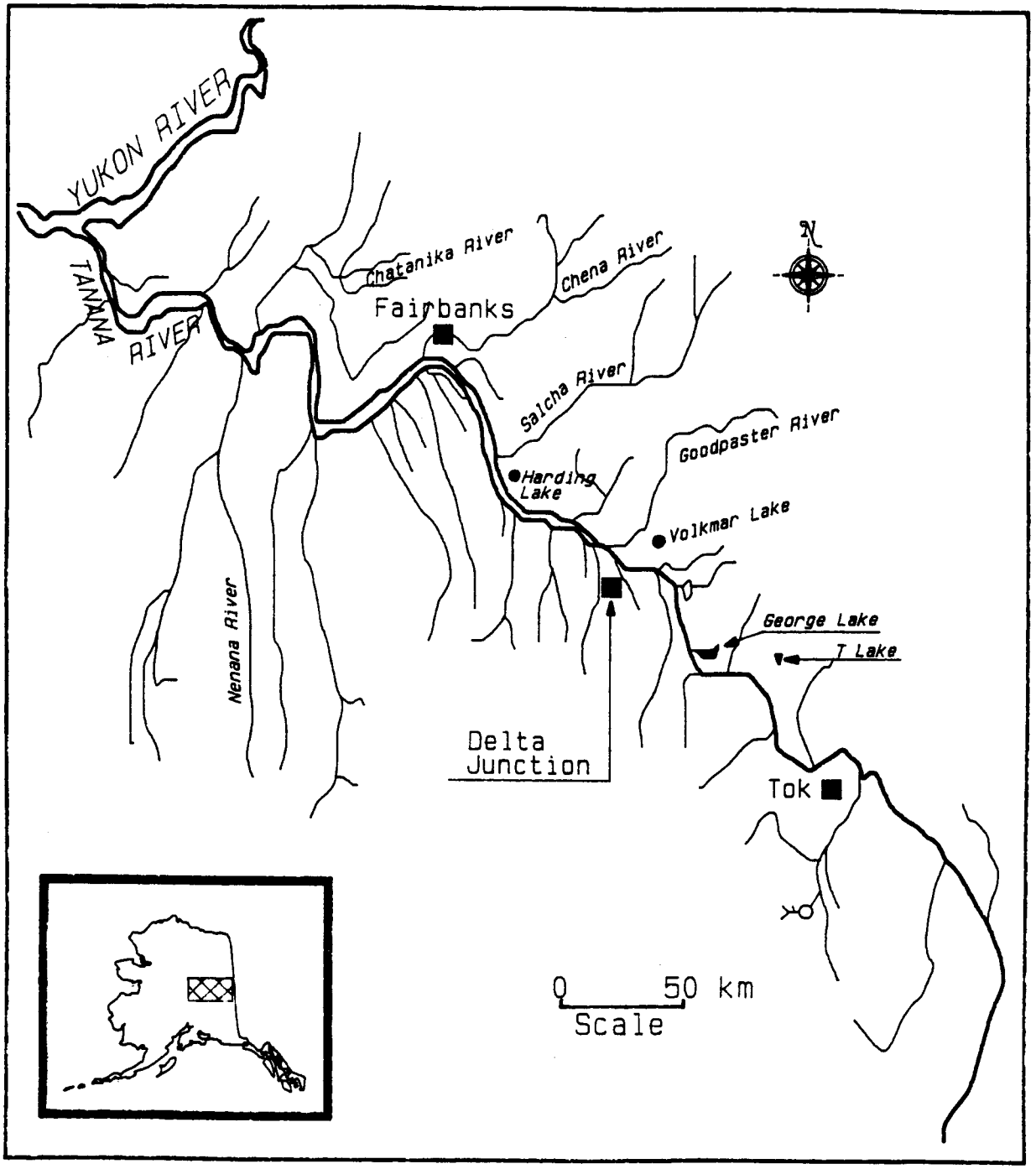

Figure 1. Location of Volkmar, George, and T lakes, Alaska.

Fishing pressure in Volkmar Lake has ranged from slightly below one to over two angler days annually per ha (Figure 2). Volkmar Lake is popular because of recent land disposals around the lake by the State, improved winter access from new snow machine trails and roads in the Delta Agricultural Project, and increased summer and winter use by cabin owners around the lake and on the nearby Goodpaster River.

The research program on northern pike in Volkmar Lake began in 1985, with initial efforts focused on obtaining an abundance estimate. In 1986, several gear types and deployment techniques were evaluated to identify a non-lethal, efficient sampling method for the capture of northern pike. Seines proved to be the most effective capture gear of those evaluated (gill nets, various trap and fyke nets, and seines) for study of this northern pike population (Peckham and Bernard 1987).

George Lake (63°47′N, 144°31′W) is a semi-remote 1,823 ha (4,505 ac) lake located approximately 8 km northeast of the Tanana River and the Alaska Highway about 45 km southeast of the town of Delta Junction (Figure 1). The lake is accessible during the open water season by either float-equipped aircraft, or boat via the Tanana River and then the outlet, George Creek. Although George Creek is navigable, it is shallow, requiring a boat powered with a jet unit or an outboard equipped with a lift device. Snow machines and ski-equipped aircraft provide winter access.

George Lake lies at an elevation of 389 m and has a maximum depth of 11 m. The lake has one major inlet, six smaller inlets, and a navigable outlet, George Creek, which flows to the south into the Tanana River. Near-shore waters are shallow with beds of aquatic vegetation providing spawning and rearing substrate for northern pike. George Lake is typically ice-free from late-May to mid-October, and spawning of northern pike generally coincides with the beginning of the ice-free period and continues for up to two weeks, into early-June. Anglers at George Lake target northern pike, although other fish species are present including Arctic grayling *Thymallus arcticus*, burbot *Lota lota*, humpback whitefish, least cisco, round whitefish *Prosopium cylindraceum*, longnose suckers *Catostomus catostomus*, and slimy sculpin. Fishing pressure in George Lake has ranged from 0.3 to 1.1 angler days annually per ha (Figure 2). Northern pike investigations in George Lake began in the early 1970's with limited composition sampling of angler-harvested fish (Peckham 1972-1986). The current research program on northern pike began in 1986 with an assessment of efficient capture gear and sampling locations (Peckham and Bernard 1987). The abundance and composition of the northern pike population in this lake have been estimated annually since 1987 (Clark et al. 1988; Timmons and Pearse 1989, and Pearse 1990).

T Lake (63°48′N, 143°53′W) is a remote fly-in lake located approximately 18 km north of Dot Lake village along the Alaska Highway (Figure 1). The 158 ha (390 ac) lake lies at an elevation of 434 m and has a maximum depth of 17 m. The lake has two small inlets and an intermittent outlet that flows from the northeast corner into Billy Creek, a tributary of the Tanana River to the south. Near-shore waters are shallow with beds of aquatic vegetation providing spawning and rearing substrate for northern pike. T Lake is typically ice-free from mid-May to early October, and spawning of northern

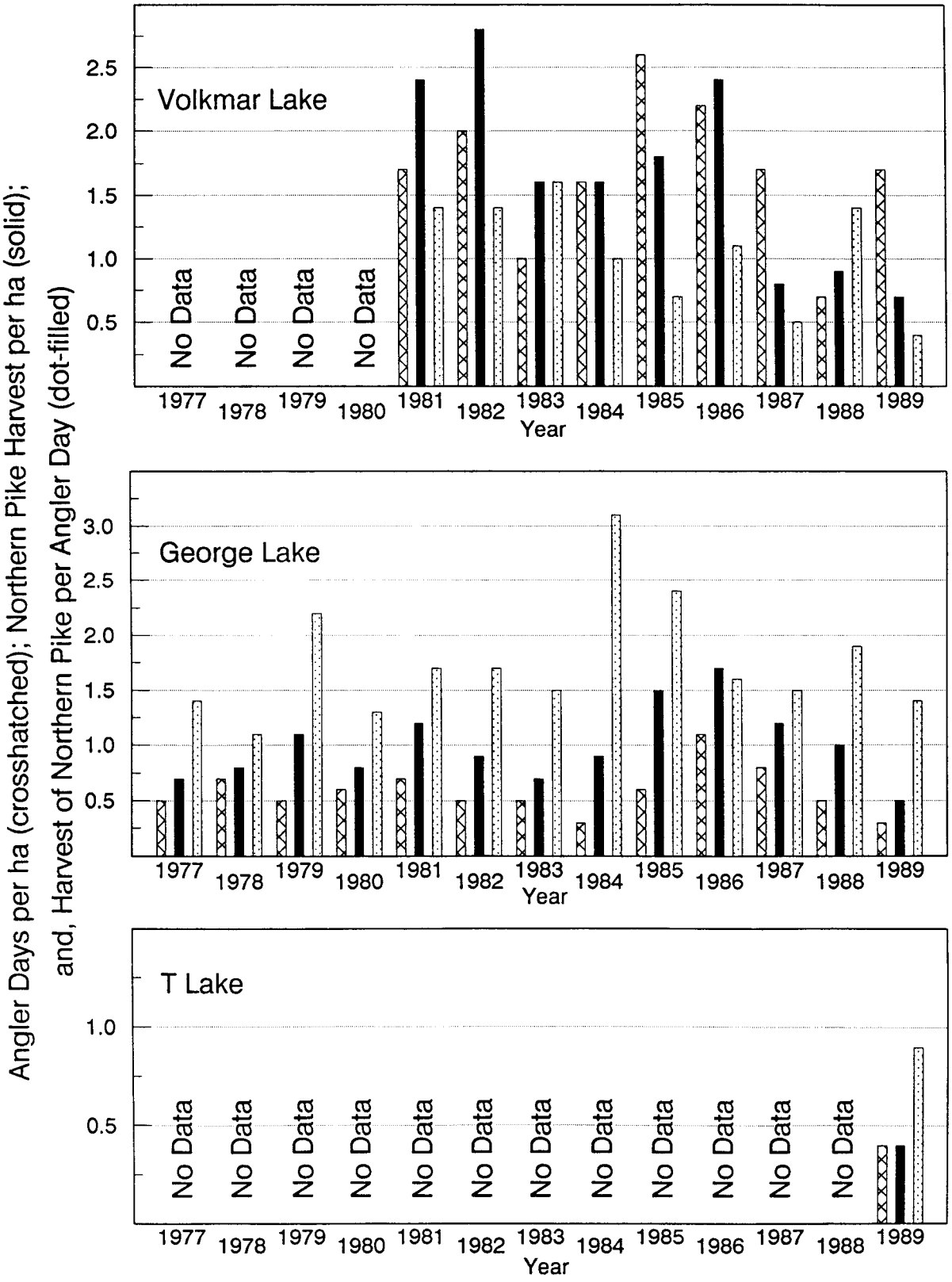

Figure 2. Recreational fishing effort, harvest, and exploitation of northern pike in Volkmar, George, and T lakes, 1977-1989.

pike generally coincides with the beginning of the ice-free period and continues for up to two weeks, into late May. Other fish species in the lake include burbot, humpback whitefish, and least cisco.

Fishing pressure is believed to be low, but exploitation rates high, compared with other area waters (Figure 2; Table 1). Life history and abundance studies of northern pike have been conducted annually since 1986 (Peckham and Bernard 1987, Clark 1988, Timmons and Pearse 1989, and Pearse 1990).

Study Goals and Objectives

The overall study goals are to estimate the ranges of population abundance, recruitment, and composition over several years in Volkmar, George, and T lakes. This data, along with estimates of survival of fully recruited spawning cohorts, and sport harvest, will permit the development of techniques necessary to balance recreational demands with surplus production and desired composition in Alaskan northern pike populations. Results to date include estimates of northern pike abundance, composition, survival, and recruitment. An improved understanding of age structure, growth, sex composition, and population dynamics of northern pike stocks has resulted from this program.

Specific objectives of the 1990 research program (F-10-6 contract) were to estimate:

1. abundance of northern pike in Volkmar, George, and T lakes during 1990; and,

2. length, age, and sex composition of northern pike populations in each lake.

In addition, the program in 1990 addressed left-over objectives from 1989 (the F-10-5 contract), which were to estimate the 1989 abundance and population composition of northern pike in Volkmar and T lakes. These objectives were not achieved at the close of the F-10-5 contract, and consequently were addressed in the F-10-6 contract.

Specific objectives of the 1991 research program (F-10-7 contract) were to estimate:

1. abundance of northern pike in Volkmar, George, and T lakes during 1991; and,

2. length, and age composition of northern pike populations in each lake.

This report also presents historic estimates of abundance by size-class and cohort, density, age and length composition, mean length-at-age, survival, recruitment, and harvest of the northern pike populations in these waters.

METHODS

Study Design

Population sampling and mark-recapture experiments for northern pike were conducted in the three study lakes (Volkmar, George, and T) from mid-May to early June during 1990 and 1991. Prior experience indicated that population studies of northern pike in interior Alaskan lakes are best conducted during the spawning period, immediately following spring ice melt when northern pike are concentrated and low water temperatures minimize temperature-sensitive handling injuries (Peckham and Bernard 1987, Clark 1988). Peak spawning activity, as reflected by both observation of fish activity and catch of ripe fish in gill nets and seines, occurs during mid-day, generally between 1000 and 2000 hours. Sampling efforts were therefore focused to include this peak period of daily near-shore activity.

A two-event experiment was conducted in Volkmar Lake during 1990 (Appendix A). A four-day marking event (16 May to 19 May) was followed by a three-day recapture event (22 May to 24 May). In George Lake during 1990, two sampling events occurred: a six-day marking event (31 May to 5 June) and a four-day recapture event (9 June to 12 June). In T Lake, a single-day mark event (18 May) was followed by a two-day recapture event (20 May to 21 May).

During 1991, a two-event experiment was again conducted in Volkmar Lake (Appendix A). A six-day marking event (20 May to 25 May) was followed by a three-day recapture event (28 May to 30 May). In George Lake, two discrete sampling events occurred: a three-day marking event (24 May to 26 May) and a seven-day recapture event (30 May to 5 June). In T Lake, a two-day mark event (20 May to 21 May) was followed by a two-day recapture event (24 May to 25 May).

Planned sample sizes were determined according to procedures in Robson and Regier (1964). Fish were captured in Volkmar and George lakes with a bag seine, 66 m long and 3 m deep with 25 mm square mesh, set from a boat and retrieved by hand to the shore by a crew of four or five. Seines were normally set in water less than 2 m deep in known spawning areas, usually within 100 m of the shore. Gill nets were used in T Lake to capture northern pike because of previous limited success with seines (Pearse 1990). Six-panel 46 m gill nets, both floating and sinking, with two-each panels of 25, 38, and 51 mm bar mesh multifilament netting dyed green, were set in spawning areas. Up to seven nets per two-person crew were employed during peak daily fish activity periods. Frequent gill net checks (hourly) minimized handling mortality (for additional gear specifications and gear fishing patterns see Peckham and Bernard 1987).

Data Collection

All data regarding age, sex, length, tag number and color, and body marks were recorded on Tagging Length Version 1.0 mark-sense forms during the sampling process. As required, one or more new forms were processed for each seine haul or gill net set per-day during which northern pike were successfully captured. Hauls or sets were numbered sequentially through the experiment,

regardless of success of capture. Location of each haul or set was recorded on lake maps (Figure 3), with a separate map used each sampling day. Each lake was divided into two areas (Volkmar (1991) and T lakes) or three areas (Volkmar (1990) and George lakes) for later hypothesis testing concerning mixing during the mark-recapture experiments.

Past studies have shown that subsamples of length, sex, and age measurements from northern pike captured can be biased toward larger fish (Clark 1988). Therefore, each fish captured (including within-season recaptures) during the respective sampling events was measured for fork length (FL) to the nearest mm, sex was recorded if determined, and scale samples were taken. Northern pike were released at least 100 m away from the capture location to minimize within-event recapture.

All captured northern pike were examined for tags. All fish were examined for evidence of fin clips and/or opercle punches. Fish captured in this long-term study have been double-marked to aid in detecting within and between year tag loss. Marking codes used in all lakes during 1990 and 1991, plus those from prior sampling events, are detailed in Appendix B. Untagged northern pike judged to be in a healthy condition were released after being marked with a Floy FD-68 internal anchor tag inserted posteriorly at the left base of the dorsal fin during all sampling events. A hole on the right opercle cover of each fish was created with a standard paper punch as a second mark in 1990, and a dorsal fin-clip was applied in 1991. The importance of identifying all punches/fin clips (Appendix B) was stressed to field crews. When possible, the sex of each live fish was determined by the presence of sex products or by external characteristics as described in Casselman (1974). Fish for which sex could not be determined were recorded as neither male nor female.

Scales were removed from each fish captured. A minimum of three scales were taken from the preferred zone adjacent to, but not on, the lateral line above the pelvic fins as described by Williams (1955). Scales were placed in individual coin envelopes marked with the appropriate mark-sense form litho-code and sample number. Scales were removed from coin envelopes in the laboratory, cleaned, and two non-regenerated scales per fish were mounted on gummed cards. The cards were used to make scale impressions on 20 mil acetate sheets using a Carver press at 137,895 kPa (20,000 psi) heated to 93°C for one minute. Scales were read on a microfiche reader (32x) and ages recorded in accordance with age identification criteria established by Williams (1955) and Casselman (1967). Because experience has shown that the formation of scale annuli in Alaskan stocks of northern pike generally coincides with or closely follows our sampling period in late May, ages were assigned to match the observed annuli. In the case of individually excessive circuli plus growth (> 8 circuli since last annulus), a year was added. All dead fish were dissected to verify sex and maturity through examination of the gonads. Scales, vertebrae, and cleithra were taken from each dead fish for later determination of age.

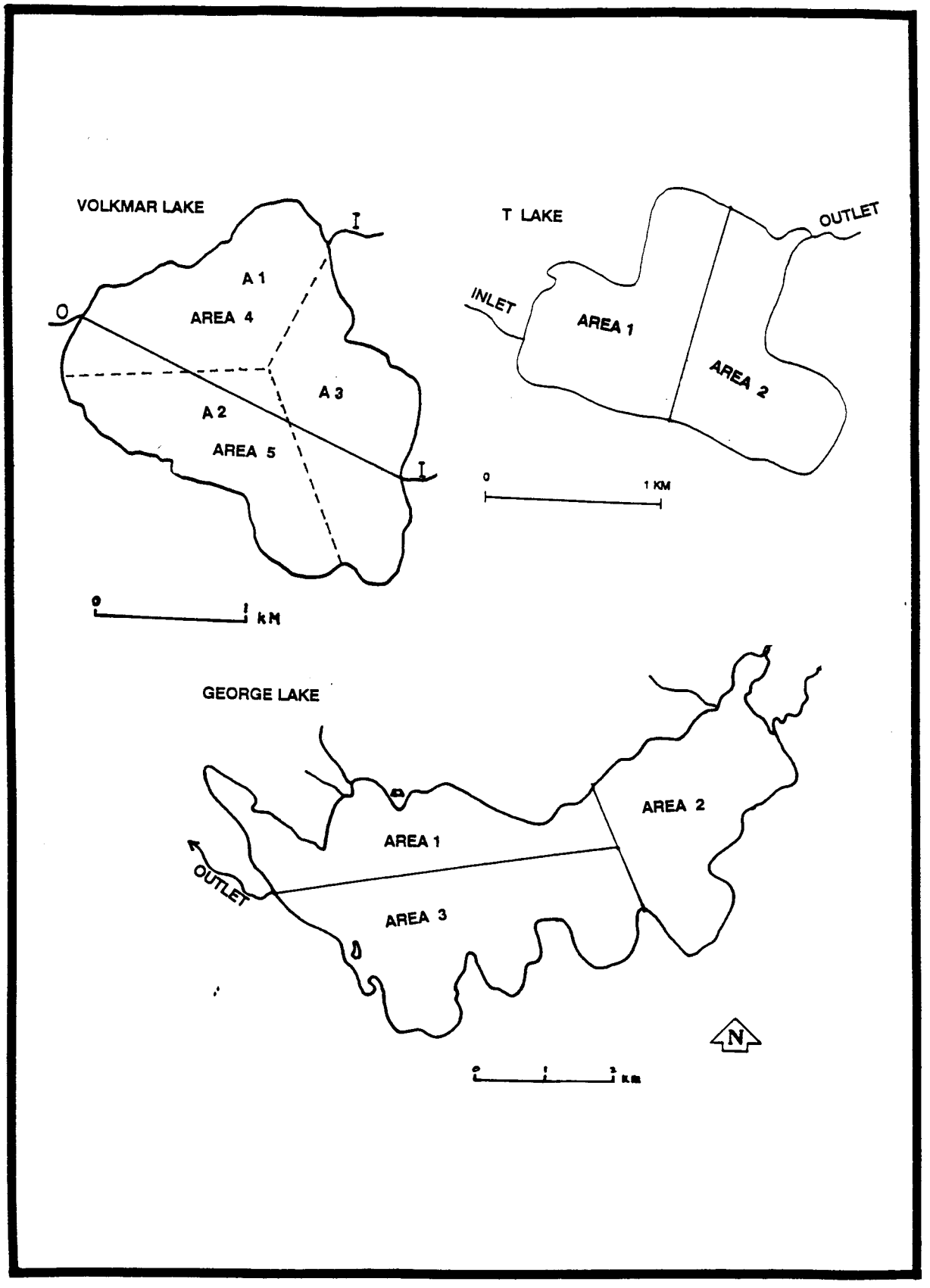

Figure 3. Sampling areas in Volkmar, George, and T lakes, Alaska, 1990 and 1991. Dashed lines indicate 1990 sampling areas for Volkmar Lake (A1, A2, and A3).

Data Analysis

Data collected from northern pike in Volkmar, George, and T lakes were analyzed and estimates of abundance and age, sex, and length compositions were calculated.

Abundance Estimation:

The Chapman modification of the Petersen single-mark method was used to estimate the abundance of northern pike in all three lakes in 1990 and 1991 (Seber 1982). The abundance estimates are relevant to the time immediately after the marked fish were released. Conditions for the accurate use of the Petersen estimator are:

1. marking does not effect the catchability of the fish;

2. marked fish do not lose their marks between sampling events;

3. recruitment *and* mortality do not occur between sampling events; and,

4. every fish has an equal probability of being marked and released alive during the first event; *or* every fish has an equal probability of being captured during the second event; *or* marked fish mix completely with unmarked fish between sampling events (Seber 1982).

Whether or not a fish received a Floy tag should not affect its chances of being caught in the sampling gear. Double marking of northern pike insured the second assumption was not violated. The assumption of no recruitment nor mortality is considered valid because of the hiatus (between two and four days) that occurred between the marking event and the recapture event. Sampling effort was evenly distributed throughout the various lakes in an attempt to meet the fourth assumption and, the hiatus should have allowed for sufficient mixing between marked and unmarked fish.

To detect size-selectivity during the mark and recapture events, two 2-sample Kolmogorov-Smirnov tests (Zar 1984) were conducted. The first compared the distribution of lengths of northern pike marked during the first event to lengths of fish recaptured during the second event. The second test compared the distribution of lengths of fish caught in the marking event with the distribution of fish caught in the second event. The outcome of these tests determined if the abundance estimates needed to be stratified into different length groups and abundance estimated separately for each stratum as suggested by Ricker (1975), and as described in Appendix C.

Two contingency tables (Seber 1982) were used to determine if the fourth assumption had been met. The first table, which compared the recapture to catch ratio (R/C) from each area, tested whether the recapture rate was the same between areas. The second table, which compared the area of release to the area of recapture was used to determine if northern pike from different areas mixed. If complete mixing occurred and the recapture rate was the same between areas, then the fourth assumption was met and the Petersen estimator was used. If the contingency tables showed that only partial mixing occurred,

the abundance estimator suggested by Darroch (1961) was used and the variance was approximated with bootstrap techniques (Clark et al. 1988). If no mixing occurred between one or more lake areas, a separate Petersen estimate of abundance was calculated for each area.

When all conditions were met, abundance ($\hat{N}$) and variance $\hat{V}[N]$ for the Petersen estimate were calculated according to the following equations:

$$\hat{N} = \frac{(C+1)(M+1)}{(R+1)} - 1; \text{ and,} \quad (1)$$

$$\hat{V}[N] = \frac{\hat{N}(C-R)(M-R)}{(R+1)(R+2)}; \quad (2)$$

where:

M = the number of fish marked during the first event;

C = the number captured during the second event; and,

R = the number captured during the second event with marks from the first event.

The assumptions for the Petersen estimator are for a population closed to recruitment and mortality. Whenever a population was not closed, a non-parametric test designed by Robson and Flick (1965) was used to detect and cull significant growth recruitment.

Abundance was estimated as:

$$\hat{N} = (M + 1)(\bar{u}_r + 1) - 1; \quad (3)$$

$$\bar{u}_r = \frac{\sum_{k=r}^{R} u_k}{a}; \quad (4)$$

$$\hat{V}[N] = (M + 1)^2 \, V[\bar{u}_r]; \text{ and,} \tag{5}$$

$$V[\bar{u}_r] = \frac{\sum_{k=r}^{R} (u_k - \bar{u}_r)^2}{a(a - 1)} \tag{6}$$

where:

u_k = the number of unmarked fish of length longer than the k_{th} largest recaptured fish but shorter than the length of the (k_{th} + 1) recaptured fish;

r = the rank of the recaptured fish beyond whose length no significant growth recruitment occurred;

u_r = the mean of the u_k when $k > r$;

a = R - r + 1.

Composition Estimation:

Abundance estimates and data pertaining to sex, length, age composition were used to apportion northern pike populations into the following categories:

1. "Small" (300-449 mm), "Medium" (450-749 mm), "Large" (750 mm and larger), and "All northern pike greater than 449 mm" (this was done to facilitate annual comparisons among and between all lakes studied). The abundance estimates for fish over 299 mm were supplemented by redefining all data collected to date into these additional component size categories and estimating both abundance, proportions and standard errors;

2. Relative Stock Densities (RSD; Gabelhouse 1984) in "stock" (300-524 mm), "quality" (525-654 mm), "preferred" (655-859 mm), "memorable" (860-1,079 mm), and "trophy" (> 1,079 mm) FL classes;

3. sex composition by length category; and,

4. abundance by age.

When abundance estimates were not stratified due to size-selectivity of the sampling gear, composition estimates were calculated as follows:

$$p_j = n_j/n \tag{7}$$

where:

n = the number of fish sampled for information on age, length, or sex composition;

n_j = the number of sampled fish in group j; and,

p_j = the estimated fraction of the fish in group j.

The variance of the proportion was calculated as:

$$V[p_j] = \frac{p_j(1 - p_i)}{n - 1} \tag{8}$$

The estimated number of northern pike by length group was calculated as:

$$\hat{N}_j = \hat{p}_j \hat{N} \tag{9}$$

The variance for $\hat{N}_j$ was calculated as a sum of the exact variance of a product from Goodman (1960):

$$\hat{V}[N_j] = \hat{V}[p_j]\hat{N}^2 + \hat{V}[N]\hat{p}_j^2 - \hat{V}[p_j]\hat{V}[N]) \tag{10}$$

Whenever abundance estimates were stratified because of size selectivity in the sampling gear, estimates of length and age compositions were calculated as follows:

$$p_{ij} = n_{ij}/n_i \tag{11}$$

where:

n_i = the number of fish sampled from length category i in the mark-recapture experiment;

n_{ij} = the number of fish sampled from length category i that belong to group j; and,

p_{ij} = the estimated fraction of the fish in group j in length category i.

The variance for p_{ij} is:

$$V[p_{ij}] = \frac{p_{ij}(1 - p_{ij})}{n_i - 1} \tag{12}$$

The estimated abundance of group j in the population (N_j) was calculated as:

$$\hat{N}_j = \sum_i p_{ij} \hat{N}_i \qquad (13)$$

where: $\hat{N}_i$ = the estimated abundance in length category i. The variance for N_j was calculated as a sum of the exact variance of a product from Goodman (1960):

$$\hat{V}[N_j] = \sum_i (V[p_{ij}]\hat{N}_i^2 + \hat{V}[N_i]p_{ij}^2 - V[p_{ij}]\hat{V}[N_i]) \qquad (14)$$

The estimated proportion of the population that belonged to group j (p_j) was calculated as:

$$\hat{p}_j = \hat{N}_j/\hat{N} \qquad (15)$$

where: $N = \Sigma N_i$. The variance of the estimated fraction was approximated with the delta method (see Seber 1982):

$$V[p_j] \approx \sum_i V[p_{ij}] \left[\frac{\hat{N}_i}{\hat{N}} \right]^2 + \frac{\sum_i \{\hat{V}[N_i] (p_{ij} - p_j)^2\}}{\hat{N}^2} \qquad (16)$$

Length frequencies were corrected for the size selectivity of gear and for growth recruitment when needed as described above.

Mean length-of-age by year reflects the mean value of summed lengths by age alone. The average mean length-at-age across years represents the mean value of annual averages weighed and summed across all years. Estimates of annual variance were similarly weighed and summed.

Survival and Recruitment Estimation:

Survival rates and recruitment were calculated as by-products of the estimation of abundance for populations in Volkmar, George, and T lakes. Age-specific survival rates were calculated as follows:

$$\hat{S}_t = \frac{\hat{N}_{t+1,y+1}}{\hat{N}_{t,y}} \qquad (17)$$

where: $\hat{S}_t$ = the survival rate of fish age t in year y to age t+1 one year later.

$\hat{N}_{t+1,y+1}$ = abundance of fish age t + 1 in year y + 1.

$\hat{N}_{t,y}$ = abundance of fish age t in year y.

The variance of $\hat{S}_t$ was approximated with the delta method (see Seber 1982):

$$\hat{V}[\hat{S}_t] \approx \hat{S}_t^2 \left[\frac{\hat{V}[\hat{N}_{t+1,y+1}]}{\hat{N}^2_{t+1,y+1}} + \frac{\hat{V}[\hat{N}_{t,y}]}{\hat{N}^2_{t,y}} \right] \quad (18)$$

Because estimates of survival were determined for only fully recruited cohorts, and because age at full recruitment to the spawning population (and our sampling methods) is probably size (and therefore growth-rate) dependent, age-specific survival rates were estimated for northern pike (sexes combined) ages 4 through 8 in George Lake, ages 5 through 9 in Volkmar Lake, and ages 6 through 10 in T Lake. When needed, the length and age data from each water-body was corrected for gear size-selectivity prior to these determinations.

Age at initial full recruitment (sexes combined) was assessed based upon the highest average abundance of the youngest cohort in each water-body over the time periods studied to date. Then, the sum of the estimated abundance of all fish at the age at full recruitment plus the three subsequent cohorts in year y and all fish of these same year-classes in year y+1 were used with equations 17 and 18 to estimate recruitment, survival rate, and their standard error. The cohort-groups were limited to four year-classes because relatively few of the male northern pike in our studies survive four years beyond their age at full recruitment (Pearse 1990).

RESULTS

Volkmar Lake

The population abundance, length and age compositions, and survival and recruitment were estimated for 1989, 1990, and 1991. The sex composition of the northern pike population was not estimated in 1990, and was not a 1991 objective.

Abundance:

Two abundance estimates were calculated for the population of northern pike in Volkmar Lake as a result of the 1990 sampling effort. Due to catchability problems experienced during the latter stages of the 1989 event, a within-season estimate of abundance was unavailable that year, as only a single event

was conducted (Pearse 1990). However, an estimate of abundance was calculated that is germane to 1989 using information collected during 1990 as the second event (Appendix A). The estimated abundance of northern pike (over 299 mm) in May 1989 (Table 2), corrected for between-year growth recruitment, was 1,330 fish (SE = 240). Density was estimated to have been 4.9 northern pike per ha. Tests for gear selectivity within events proved significant (1989, 1990 Kolmogorov-Smirnov two-sample test, P = 0.008) the significance is probably due to normal growth between years. The between-year test for mixing ($\chi^2 = 0.225$, df = 1, $P > 0.05$) proved negative. In 1989, 580 unique northern pike were released. Of 627 examined in 1990, 59 (9.4%) were recaptures from the 1989 event. Included in the 1990 sample of 627 northern pike were fish that had recruited to the population through growth. The following values were used with equations 3 and 4 to correct for growth recruitment in the 1990 recapture event:

$$\hat{N} = (580+1)\ (1.29 + 1) - 1; \text{ and,}$$

$$\hat{V}[N] = (580+1)^2\ (0.17)$$

Based upon the 1990 within-season mark recapture experiment, there were an estimated 4,038 (SE = 714) northern pike over 299 mm in Volkmar Lake during May 1990. The estimated density was 14.8/ha. During the first event, 370 unique northern pike were captured and released (Appendix A). After a two-day hiatus in sampling, 282 northern pike were captured and examined, and of those, 25 (8.9%) were recaptures from the first event.

Prior to developing the 1990 estimate, several assumptions were tested. None of the recaptured fish had lost their tags, and the short interval between events assured population closure. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike. Since fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the three lake sampling areas ($\chi^2 = 0.675$, df = 2, $P > 0.05$), it was concluded that either marked fish mixed completely between events, or probabilities of capture during the first event were the same throughout the lake.

Comparison of the length distribution of fish marked during the first event in 1990 with the length distribution of fish recaptured during the second event showed that size-selectivity of the sampling gear during the second event was significant (Kolmogorov-Smirnov two-sample test, D = 0.38, n = 395, P = 0.003). Also, the length distribution of all fish captured during the second event was significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, D = 0.06, n = 652, P = < 0.001), indicating size-selectivity in the sampling gear occurred during the second event; the status of the size-selectivity during the first event was unknown. As a result of these tests, a Case IV (Appendix C) situation was indicated. To alleviate the detected bias due to gear selectivity, both a stratified estimate (N = 4,038; SE = 714) with two strata (300-449 and 450 mm and greater), and an unstratified estimate (N = 4,196; SE = 1,189) were

Table 2. Abundance and density of various size groups of northern pike (> 299 mm FL) in Volkmar, George, and T lakes, 1985-1991.

Lake/ Year	Small (300-449 mm) Abundance Estimate	SE	Proportion Estimate	SE	Medium (450-749 mm) Abundance Estimate	SE	Proportion Estimate	SE	Large (Larger than 749 mm) Abundance Estimate	SE	Proportion Estimate	SE	All (Larger than 299 mm) Abundance Estimate	SE	Density (Fish/Ha)	All (Larger than 449 mm) Abundance Estimate	SE	Proportion Estimate	SE	Density (Fish/Ha)
Volkmar																				
1985	---	---	---	---	3,732	201	---	---	288	24	---	---	---	---	---	4,020	250	---	---	15
1986	4,028	2,266	0.50	0.006	3,891	584	0.48	0.006	137	65	0.02	0.001	8,056	2,915	29.5	4,028	587	0.50	0.006	14.8
1987	2,703	641	0.39	0.006	4,118	634	0.59	0.006	111	22	0.02	0.002	6,932	1,542	25.4	4,230	634	0.61	0.006	15.5
1988	570	64	0.21	0.008	2,135	147	0.77	0.008	61	19	0.02	0.003	2,766	177	10.1	2,196	148	0.79	0.008	8.0
1989	215	43	0.16	0.010	974	177	0.73	0.012	141	30	0.11	0.008	1,330	240	4.9	1,115	179	0.84	0.010	4.1
1990	2,019	372	0.50	0.026	1,866	346	0.46	0.026	153	48	0.04	0.010	4,038	714	14.8	2,019	349	0.50	0.028	7.4
1991	2,001	253	0.44	0.018	2,276	285	0.51	0.018	233	46	0.05	0.008	4,510	541	16.5	2,509	289	0.56	0.020	9.2
George																				
1987	9,167	978	0.52	0.004	8,195	1,031	0.46	0.004	300	342	0.02	0.001	17,662	2,105	9.7	8,495	1.086	0.48	0.004	4.7
1988	8,264	2,310	0.35	0.003	14,705	4,083	0.63	0.003	412	145	0.02	0.001	23,381	6,471	12.8	15,117	4,086	0.65	0.003	9.1
1989	13,112	1,710	0.51	0.003	11,845	1,471	0.47	0.003	509	67	0.02	0.001	25,466	3,157	14.0	12,354	1,473	0.49	0.003	6.9
1990	3,461	412	0.30	0.004	7,946	891	0.69	0.004	161	43	0.01	0.001	11,568	1,277	6.3	8,107	892	0.70	0.004	4.4
1991	5,005	473	0.31	0.009	10,496	957	0.66	0.009	443	65	0.03	0.003	15,944	1,436	8.7	10,939	959	0.69	0.009	6.0
T																				
1986	---	---	---	---	412	37	---	---	42	5	---	---	---	---	---	454	37	---	---	2.9
1987	107	18	0.17	0.015	452	53	0.73	0.018	64	13	0.10	0.012	623	70	3.9	516	54	0.83	0.015	3.3
1988	73	12	0.16	0.017	350	34	0.75	0.020	42	9	0.09	0.013	465	43	2.9	392	35	0.84	0.017	2.5
1989	27	9	0.09	0.017	247	25	0.83	0.022	24	9	0.08	0.016	298	31	1.9	271	27	0.91	0.017	1.7
1990	46	12	0.13	0.018	286	37	0.82	0.020	15	7	0.04	0.011	347	42	2.2	301	38	0.87	0.018	1.9
1991	40	9	0.12	0.025	264	32	0.81	0.030	24	7	0.07	0.020	328	54	2.1	288	33	0.88	0.036	1.8

calculated. Because both estimates were similar, the estimate with the larger variance was discarded.

Based upon the 1991 within-season mark recapture experiment, there were an estimated 4,510 (SE = 541) northern pike over 299 mm in Volkmar Lake during May 1991 (Table 2). The estimated density of northern pike was 16.5/ha. During the first event (Appendix A), 739 unique northern pike were captured and released. After a two-day hiatus in sampling, 322 northern pike were captured and examined, of which 52 (16%) were recaptures from the first event. During 1991, 252 (34%) were marked and released in Area 4, and 487 (66%) were marked and released in Area 5 (Figure 3). During the second event, 283 (88%) northern pike were captured in Area 4, and 39 (12%) were captured in Area 5.

Prior to developing the 1991 estimate, several assumptions were tested. An insignificant number (2, 0.3%) of the recaptured fish had lost their tags, and the short interval between events assured population closure. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike; none of the northern pike handled during 1991 died during the sampling program. Since fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the two lake sampling areas ($\chi^2 = 0.890$, df = 1, $P > 0.05$), it was concluded that either marked fish mixed completely between events, or probabilities of capture during the first event were the same throughout the lake. When the area of marked-fish release was compared with area of recapture, the result showed sufficient mixing.

Comparison of the length distribution of fish marked during the first event with the length distribution of fish recaptured during the second event showed that size-selectivity of the sampling gear during the second event was significant (Kolmogorov-Smirnov two-sample test, D = 0.25, n = 791, $P = < 0.006$). Also, the length distribution of all fish captured during the second event was significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, D = 0.22, n = 1,061, $P = < 0.001$), indicating size-selectivity in the sampling gear occurred during the second event; the status of the size-selectivity during the first event was unknown. As a result of these tests, a Case IV (Appendix C) situation was indicated. To alleviate the detected bias due to gear selectivity, both a stratified estimate (N = 5,038, SE = 1,146) with three strata (300-449, 450-624, and 625 mm and greater), and an unstratified estimate (N = 4,510, SE = 541) were calculated. Because both estimates were similar, the estimate with the larger variance (stratified estimate) was discarded.

Non-overlapping confidence intervals indicated a significant increase in abundance (for all fish > 299 mm) between 1989 and the abundance estimated in both 1990 and 1991. The 1990 and 1991 abundance estimates were statistically similar.

Composition:

The source for the 1989 composition estimates was all unique fish examined in 1989. In 1990, only the lengths, ages, and sexes from the second event were used to estimate proportions in composition (Appendix C, Case IVa), because of

the size-selectivity described above. In 1991, only the lengths, ages, and sexes from the first event were used to estimate proportions in composition (Appendix C, Case IVb), because of the size-selectivity also described above.

The estimated abundance and proportion of northern pike in the small size category (Table 2) significantly declined from 1986 to 1989 (from 50% to 10%). This category is mainly comprised of partially recruited northern pike. Fish in the medium size range predominated in all years. The abundance and proportion of northern pike in the medium and large categories were summed to estimate the abundance of all fish over 449 mm, and numbered an estimated 1,115 (SE = 179) northern pike in 1989, 2,019 (SE = 349) northern pike in 1990, and 2,509 (SE = 289) in 1991. This group consisted primarily of fish fully recruited to the spawning population (age 5 and above in Volkmar Lake). In Volkmar Lake, male northern pike are generally absent from the large size category.

Estimated RSDs differed between 1989 and 1990 (Table 3), but probably not between 1990 and 1991. Increases were evident in the stock category due to recruitment to the spawning population in 1990 (Figure 4).

The length frequency distribution of sampled northern pike (sexes combined) peaked between 550 and 600 mm in 1989 (Table 4). In 1990, northern pike demonstrated a strong mode between 275 and 375 mm, and a secondary but weaker mode between 575 and 625 mm. In 1991, sampled fish in the 375 to 399 mm length class were most abundant. Approximately fifty percent of the sampled northern pike were included in the 550 to 574 mm or smaller length classes in 1989, the 325 to 349 mm or smaller classes in 1990, and in the 425 to 449 mm or smaller length classes in 1991.

In 1989, 1990, and 1991, northern pike of both sexes grew between successive ages (Table 5).

The sex composition of the Volkmar Lake northern pike population was not estimated for the years 1989 through 1991. However, the composition of sampled fish (Table 5), indicated males comprised 31%, females comprised 37%, and "sex unknown" fish comprised 32% in 1989. In 1990, the proportions of sampled northern pike were 26% male, 9% female, and 64% "sex unknown". In 1991, proportions of sampled northern pike were 20% male, 12% female, and 68% "sex unknown".

In 1989, the age 6 cohort was highest in abundance (354) using sex-combined data (Table 6). In 1990, ages 3 and 6 cohorts predominated in abundance. The age 3 cohort was estimated to be most abundant in 1991 (Figure 5). The large numbers of age 3 and age 4 fish in 1991 is encouraging, as it likely indicates a favorable abundance of partially recruited northern pike in this population.

Survival and Recruitment:

The ages selected for survival analysis, 5 to 8 in year y and 6 to 9 in year y+1 in Volkmar Lake, were chosen over older cohort-groups because male northern pike appear to fully recruit to the sampling program and the spawning population by age 5, a year earlier than females, and few captured appear to

Table 3. Percent Relative Stock Densities (RSD) and abundance of northern pike (299 mm FL) in Volkmar, George, and T lakes, 1986-1991.

Lake	1986 RSD[a]	1986 SE	1986 Abundance	1986 SE	1987 RSD[a]	1987 SE	1987 Abundance	1987 SE	1988 RSD[a]	1988 SE	1988 Abundance	1988 SE
Volkmar												
Stock	59	12.0	4,719	2,269	65	4.2	4,496	1,056	48	2.3	1,316	106
Quality	34	2.7	2,730	413	28	4.2	1,976	317	39	2.3	1,080	94
Preferred	7	0.8	562	91	6	0.9	412	64	12	1.6	352	49
Memorable	1	0.3	45	23	1	0.2	48	12	1	0.4	18	11
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100		8,056	2,915	100		6,932	1,542	100		2,766	177
George			[b]									
Stock	69	2.4	---	---	74	1.6	13,123	1,589	64	1.5	15,011	4,168
Quality	23	2.2	---	---	21	1.5	3,709	514	27	1.4	6,196	1,743
Preferred	8	1.5	---	---	5	0.8	830	172	9	0.9	2,081	610
Memorable	0	---	---	---	0	---	---	---	0	---	---	---
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100				100		17,662	2,105	100		23,381	6,471
T			[c]									
Stock	14	1.6	---	---	40	2.9	248	33	37	3.0	173	21
Quality	44	2.4	---	---	27	2.6	166	25	35	2.9	161	20
Preferred	41	2.3	---	---	31	2.8	197	28	26	2.7	120	17
Memorable	1	0.5	---	---	2	0.8	11	5	2	0.9	10	4
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100				100		623	70	100		465	43

-continued-

Table 3. (Page 2 of 2).

Lake	1989 RSD[a]	1989 SE	1989 Abundance	1989 SE	1990 RSD[a]	1990 SE	1990 Abundance	1990 SE	1991 RSD[a]	1991 SE	1991 Abundance	1991 SE
Volkmar												
Stock	36	1.8	481	90	66	2.5	2,674	483	65	1.8	2,939	361
Quality	44	1.9	581	107	25	2.3	1,026	203	25	1.6	1,141	155
Preferred	19	1.5	247	49	8	1.4	327	81	8	1.0	350	61
Memorable	2	0.5	21	7	< 1	0.3	11	11	2	0.5	80	24
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100		1,330	285	100		4,038		100		4,510	541
George												
Stock	60	1.4	15,280	1,915	62	1.4	7,172	808	58	1.0	9,252	847
Quality	33	1.3	8,302	1,074	31	1.4	3,551	424	30	0.9	4,826	458
Preferred	7	0.7	1,834	287	7	0.8	833	130	11	0.6	1,835	193
Memorable	0	---	---	---	0	---	---	---	1	0.1	31	14
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100		25,466	3,137	100		11,567	1,277	100		15,944	1,436
T												
Stock	30	4.9	88	17	30	4.3	103	19	27	3.4	89	15
Quality	53	5.3	159	23	50	4.7	174	27	49	3.8	160	23
Preferred	16	3.9	47	13	20	3.8	70	16	23	3.2	75	13
Memorable	1	1.3	3	3	0	---	---	---	1	0.8	4	3
Trophy	0	---	---	---	0	---	---	---	0	---	---	---
Total	100		298	32	100		347	42	100		328	54

[a] Stock = 300-524 mm, quality = 525-654 mm, preferred = 655-899 mm, memorable = 860-1,079 mm, and trophy = 1,080 mm and larger (Clark 1988).

[b] Abundance unavailable; RSD's reflect sampled fish only.

[c] As above.

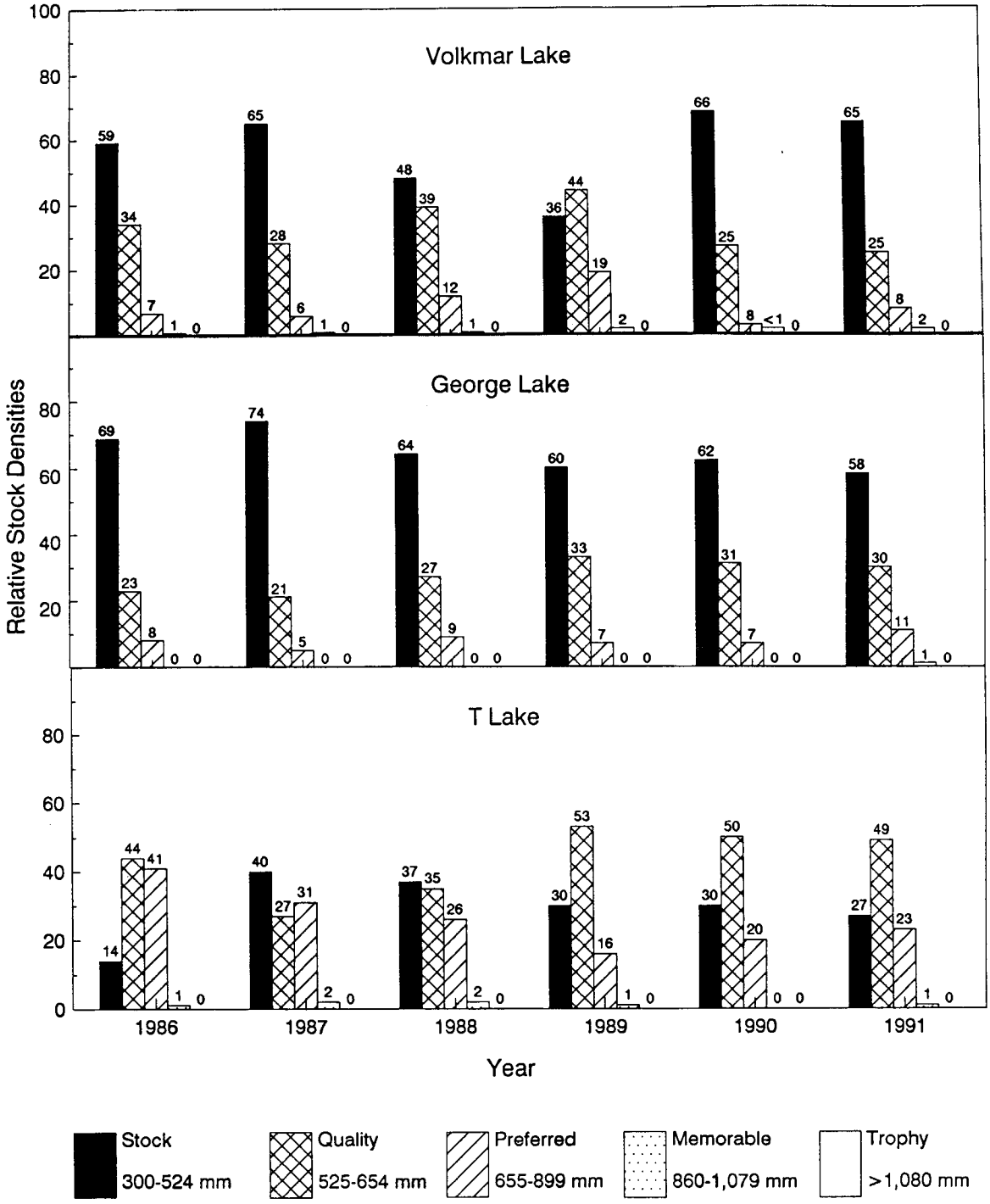

Figure 4. Estimated percent Relative Stock Densities (RSD) of northern pike populations (> 299 mm FL) in Volkmar, George, and T lakes, 1986-1991. Data for 1986 in both George and T lakes reflect sampled fish only.

Table 4. Length frequency of all northern pike sampled in Volkmar Lake, 1985-1991.

Length Class (mm)	1985		1986		1987		1988	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
< - 249	66	5.3	5	0.3	6	0.5	6	1.2
250 - 274	7	0.6	20	1.2	42	3.8	1	0.2
275 - 299	13	1.0	67	4.1	82	7.4	5	1.0
300 - 324	13	1.0	57	3.5	65	5.8	11	2.2
325 - 349	15	1.2	49	3.0	61	5.5	16	3.3
350 - 374	24	1.9	40	2.4	63	5.7	18	3.7
375 - 399	14	1.1	49	3.0	58	5.2	23	4.7
400 - 424	24	1.9	58	3.5	52	4.7	13	2.7
425 - 449	32	2.6	76	4.6	36	3.2	21	4.3
450 - 474	43	3.4	63	3.8	60	5.4	33	6.7
475 - 499	69	5.5	61	3.7	64	5.8	45	9.2
500 - 524	91	7.3	89	5.4	72	6.5	48	9.8
525 - 549	114	9.1	112	6.8	60	5.4	56	11.4
550 - 574	163	13.0	178	10.8	64	5.8	38	7.8
575 - 599	134	10.7	237	14.4	78	7.0	40	8.2
600 - 624	105	8.4	187	11.3	69	6.2	30	6.1
625 - 649	48	3.8	94	5.7	48	4.3	16	3.3
650 - 674	40	3.2	76	4.6	34	3.1	28	5.7
675 - 699	32	2.6	33	2.0	32	2.9	8	1.6
700 - 724	37	3.0	24	1.5	29	2.6	15	3.1
725 - 749	29	2.3	23	1.4	15	1.3	8	1.6
750 - 774	19	1.5	8	0.5	5	0.4	3	0.6
775 - 799	18	1.4	7	0.4	3	0.3	4	0.8
800 - 824	19	1.5	8	0.5	2	0.2	1	0.2
825 - 849	26	2.1	6	0.4	3	0.3	0	0.0
850 - 874	27	2.2	4	0.2	3	0.3	0	0.0
875 - 899	12	1.0	6	0.4	0	0.0	0	0.0
900 - 924	10	0.8	7	0.4	1	0.1	0	0.0
925 - 949	3	0.2	2	0.1	1	0.1	1	0.2
950 - 974	4	0.3	1	0.1	1	0.1	2	0.4
975 - 999	1	0.1	0	0.0	0	0.0	0	0.0
1,000 -1,024	0	0.0	2	0.1	0	0.0	0	0.0
> 1,024	0	0.0	0	0.0	4	0.4	0	0.0
Total	1,252	100.0	1,649	100.0	1,113	100.0	490	100.0

-continued-

Table 4. (Page 2 of 2).

Length Class (mm)	1989 Number	1989 Percent	1990 Number	1990 Percent	1991 Number	1991 Percent
< - 249	7	1.0	7	2.0	0	0
250 - 274	6	0.8	22	6.2	2	0.2
275 - 299	8	1.1	41	11.6	2	0.2
300 - 324	16	2.2	50	14.1	89	8.8
325 - 349	14	2.0	56	15.8	75	7.4
350 - 374	16	2.2	40	11.3	77	7.6
375 - 399	13	1.8	20	5.6	102	10.1
400 - 424	15	2.1	30	8.5	94	9.3
425 - 449	37	5.2	12	3.4	55	5.5
450 - 474	40	5.6	10	2.8	60	5.9
475 - 499	53	7.4	12	3.4	60	5.9
500 - 524	47	6.6	11	3.1	66	6.5
525 - 549	70	9.8	3	0.8	43	4.3
550 - 574	83	11.7	6	1.7	55	5.5
575 - 599	73	10.3	11	3.1	50	5.0
600 - 624	38	5.3	11	3.1	45	4.5
625 - 649	30	4.2	6	1.7	34	3.4
650 - 674	22	3.1	0	0.0	16	1.6
675 - 699	15	2.1	1	0.3	14	1.4
700 - 724	25	3.5	0	0.0	9	0.9
725 - 749	11	1.5	1	0.3	11	1.1
750 - 774	13	1.8	0	0.0	8	0.8
775 - 799	22	3.1	1	0.3	8	0.8
800 - 824	17	2.4	1	0.3	9	0.9
825 - 849	5	0.7	0	0.0	3	0.3
850 - 874	10	1.4	1	0.3	10	1.0
875 - 899	2	0.3	0	0.0	5	0.5
900 - 924	0	0.0	0	0.0	2	0.2
925 - 949	2	0.3	1	0.3	3	0.3
950 - 974	0	0.0	0	0.0	1	0.1
975 - 999	2	0.3	0	0.0	1	0.1
1,000 -1,024	0	0.0	0	0.0	0	0.0
> 1,024	0	0.0	0	0.0	0	0.0
Total	712	100.0	354	100.0	1,009	100.0

Table 5. Estimated length-at-age of northern pike (> 299 mm FL) in Volkmar Lake, 1985-1991.

	1985			1986			1987			1988		
		Fork Length (mm)			Fork Length (mm)			Fork Length (mm)			Fork Length (mm)	
Age	No. of Fish	Mean	SE	No. of Fish	Mean	SE	No. of Fish	Mean	SE	No. of Fish	Mean	SE
Males:												
2	10	288	9	1	280	---	10	289	7	1	331	6
3	23	350	10	4	351	25	125	323	5	1	309	12
4	56	472	8	8	397	28	85	414	11	2	386	8
5	48	538	5	7	542	16	127	503	8	5	508	7
6	21	565	10	9	555	11	67	558	12	4	586	7
7	21	565	9	4	597	18	28	576	10	---	---	---
8	20	591	10	3	562	8	18	613	19	1	558	42
9	21	665	14	5	618	32	11	612	26	---	---	---
10	6	731	12	2	713	5	3	645	53	1	659	---
11	6	706	15	---	---	---	1	741		---	---	---
12>	2	728	17	1	743	---	1	751	---	---	---	---
Total	234			44			476			15		
Females:												
2	6	301	7	---	---	---	8	293	9	---	---	---
3	5	361	12	7	295	8	67	364	9	---	---	---
4	22	503	7	13	550	20	118	458	8	---	---	---
5	39	549	5	16	558	14	148	553	7	6	559	39
6	36	582	7	9	593	19	140	609	7	5	633	35
7	26	607	8	9	548	70	60	631	10	7	687	23
8	22	669	9	6	648	16	28	667	10	1	667	---
9	26	759	11	---	---	---	24	775	22	---	---	---
10	30	806	11	5	838	33	13	781	31	---	---	---
11	19	856	10	1	727	---	14	847	30	---	---	---
12>	12	833	31	---	---	---	3	963	38	---	---	---
Total	243			56			643			19		
All Fish:												
2	16	293	7	2	292	12	45	289	6	2	318	13
3	28	352	12	11	315	13	213	337	4	27	362	12
4	78	481	7	11	439	30	242	430	6	75	443	8
5	87	543	5	23	553	11	278	524	5	124	512	8
6	57	576	7	19	578	11	215	596	5	118	565	8
7	47	588	8	14	556	45	95	607	9	50	619	13
8	42	632	9	11	617	15	47	643	10	18	642	23
9	47	717	11	5	618	32	35	704	24	5	627	25
10	36	793	11	7	802	32	17	729	28	7	737	38
11	25	820	10	1	727	---	16	805	63	---	---	---
12>	14	817	47	1	743	---	4	983	81	1	972	---
Total	477			105			1,207			427		

-continued-

Table 5. (Page 2 of 2).

Age	1989 No. of Fish	1989 Fork Length (mm) Mean	1989 Fork Length (mm) SE	1990 No. of Fish	1990 Fork Length (mm) Mean	1990 Fork Length (mm) SE	1991 No. of Fish	1991 Fork Length (mm) Mean	1991 Fork Length (mm) SE	1985-91 Average No. of Fish	1985-91 Average Fork Length (mm) Mean	1985-91 Average Fork Length (mm) SE
Males:												
2	28	321	3	5	314	6	18	322	5	73	311	2
3	82	364	5	33	349	6	127	359	4	395	347	2
4	78	414	6	24	370	7	57	412	7	310	420	4
5	80	492	6	10	457	13	21	477	16	298	488	4
6	72	532	6	9	498	19	20	532	18	202	544	5
7	37	557	11	2	453	16	10	561	10	102	563	5
8	14	619	32	1	637	---	8	573	21	65	599	10
9	4	635	88	---	---	---	4	605	48	45	638	13
10	1	756	---	---	---	---	2	599	42	15	690	13
11	---	---	---	---	---	---	---	---	---	7	711	13
12>	2	818	45	---	---	---	---	---	---	6	764	16
Total	398			84			267			1,518		
Females:												
2	9	326	7	---	---	---	---	---	---	23	308	5
3	9	438	25	---	---	---	14	434	17	102	375	7
4	32	438	24	---	---	---	16	478	13	211	462	6
5	83	538	7	1	538	16	12	524	14	305	547	4
6	135	579	7	2	539	17	18	589	11	345	593	4
7	85	622	9	1	640	37	18	651	20	206	624	6
8	59	703	12	---	---	---	15	691	28	131	685	7
9	23	770	13	---	---	---	6	859	23	79	774	9
10	12	783	29	---	---	---	2	849	78	62	800	11
11	5	796	47	---	---	---	2	961	31	41	847	13
12>	13	841	21	3	870	14	2	828	48	33	851	15
Total	465			7			105			1,538		
All Fish:												
2	79	318	2	19	315	2	39	325	3	202	310	2
3	232	362	3	105	355	3	281	369	3	897	356	2
4	185	417	5	64	405	5	194	434	5	849	432	3
5	207	511	5	28	497	8	89	491	8	836	517	3
6	256	559	5	30	552	8	102	565	7	797	572	3
7	157	602	7	17	600	13	71	611	10	451	603	4
8	84	682	11	5	646	21	51	643	14	258	652	5
9	35	723	19	4	643	34	26	721	23	157	708	9
10	15	786	23	1	743	72	13	808	24	96	778	9
11	6	767	48	---	---	---	7	814	65	55	807	21
12>	15	838	13	3	870	14	6	804	32	44	842	18
Total	1,271			620			879			4,642		

Table 6. Estimated age composition and cohort abundance of the northern pike population (> 299 mm FL) in Volkmar lake, 1985-1991.

	1985[a]				1986				1987				1988			
	No. of	Estimated			No. of	Estimated			No. of	Estimated			No. of	Estimated		
Age	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE
2	--	----	----	---	2	0.04	384	307	45	0.04	319	87	2	<0.01	13	9
3	--	----	----	---	11	0.26	2,110	1,244	213	0.22	1,500	359	27	0.06	175	34
4	--	----	----	---	11	0.17	1,394	738	242	0.24	1,648	374	75	0.18	486	60
5	90	0.31	1,238	137	23	0.16	1,262	316	278	0.23	1,611	284	124	0.29	804	80
6	59	0.21	840	112	19	0.11	924	231	215	0.15	1,021	152	118	0.28	764	77
7	49	0.17	677	99	14	0.10	824	267	95	0.06	439	73	50	0.11	324	48
8	42	0.13	525	86	11	0.07	535	169	47	0.03	176	33	18	0.04	117	28
9	47	0.09	377	65	5	0.03	243	111	35	0.02	115	24	5	0.01	32	15
10	36	0.05	179	35	7	0.04	282	107	17	0.01	51	14	7	0.02	45	17
11	26	0.03	120	27	1	0.01	49	49	16	0.01	42	12	---	---	---	---
12>	14	0.02	64	11	1	0.01	49	49	9	0.01	10	5	1	<0.01	6	6
Total	363	1.00	4,020	250	105	1.00	8,056	2,915	1,207	1.00	6,932	1,542	427	1.00	2,766	177

[a] Includes fish > 449 mm only.

-continued-

Table 6. (Page 2 of 2).

	1989				1990				1991			
	No. of	Estimated			No. of	Estimated			No. of	Estimated		
Age	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE
2	25	0.04	51	14	35	0.10	411	97	22	0.04	170	41
3	28	0.04	58	15	99	0.29	1,162	227	185	0.32	1,428	192
4	68	0.11	140	30	51	0.15	599	130	130	0.22	1,003	143
5	128	0.20	263	52	51	0.15	599	130	62	0.10	479	81
6	172	0.27	354	68	53	0.15	622	135	80	0.14	618	98
7	108	0.17	222	44	31	0.09	364	89	48	0.08	371	68
8	64	0.10	132	28	15	0.04	176	54	34	0.06	263	54
9	25	0.04	51	14	6	0.02	70	31	14	0.02	108	31
10	12	0.02	25	8	2	0.01	23	17	5	<0.01	39	18
11	5	0.01	10	5	1	< 0.01	12	12	4	<0.01	31	16
12>	12	0.02	24	7	0	---	---	---	---	---	---	---
Total	647	1.00	1,330	240	344	1.00	4,038	354	584	1.00	4,510	541

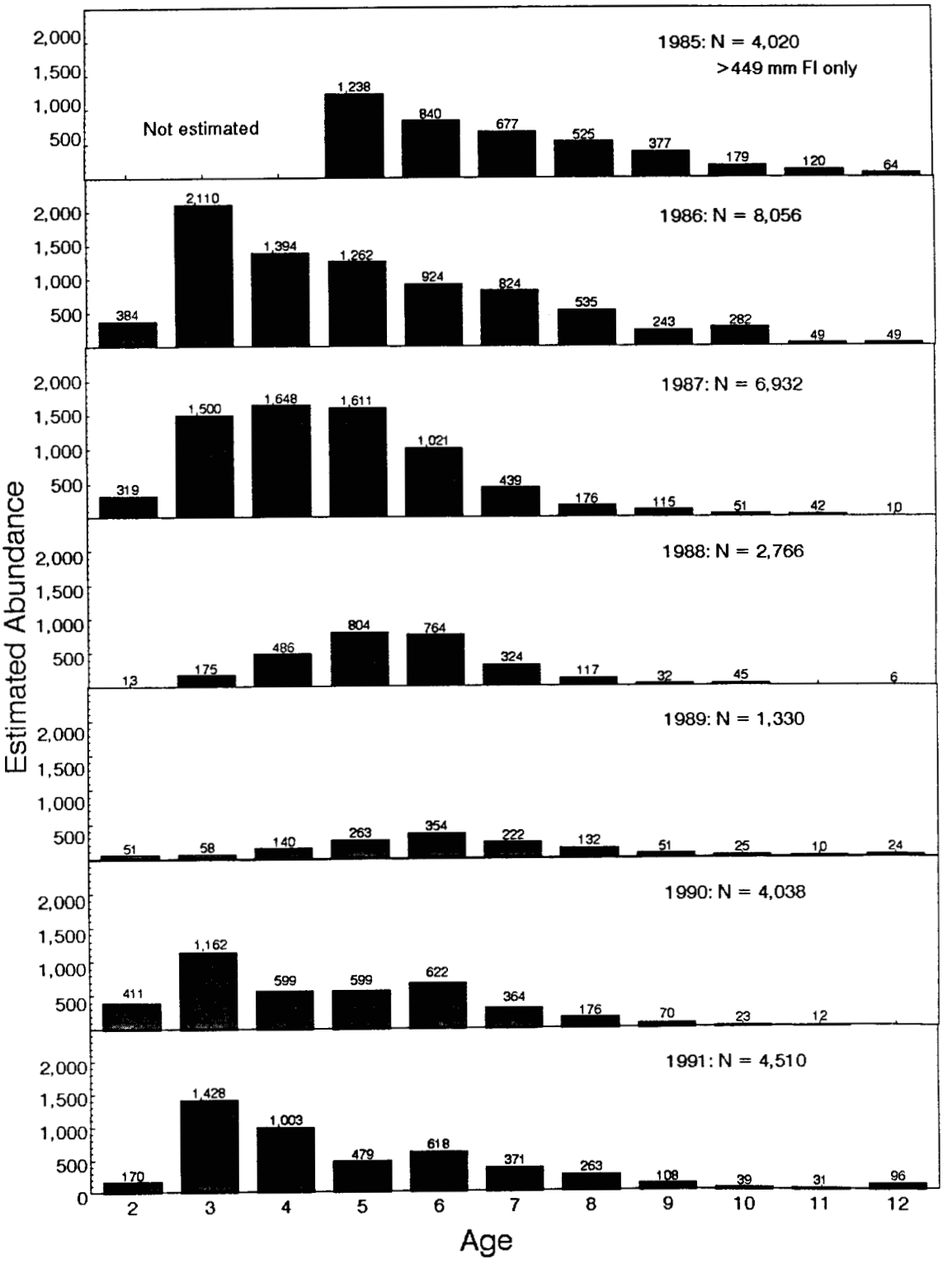

Figure 5. Estimated cohort abundance of the northern pike population (> 299 mm FL) in Volkmar Lake, 1985-1991.

survive beyond age 9 (1.8% for the sampling years 1985-1991; Table 5). Although this sex-dependent data relative to cohort recruitment is not available for all years and was not presented, it is inferred through other sources (Table 5) and contributed to the choice of what cohort-groups to select for analysis.

As shown, 38% (SE = 7) of the chosen cohorts are estimated to have survived between 1988 and 1989 (Table 7). Estimated recruitment in 1989 of age 5 northern pike was 263 (SE = 52) (Table 8). The estimated survival between 1989 and 1990 was 127% (SE = 28), which is not significantly different from 100% (α = 0.05). This result seems unlikely. Recruitment in 1990 was estimated at 599 (SE = 130) age 5 northern pike (Figure 6). Survival between 1990 and 1991 was estimated to be 77% (SE = 13), and recruitment was estimated to be 479 (SE = 81).

In 1989, 384 northern pike were tagged with green Floy tags, in 1990, 517 were tagged with blue Floy tags, and in 1991, 789 fish were again tagged with blue Floy tags in Volkmar Lake (Appendix B). The remainder of tagged fish handled in both years were recaptures from prior events. Of fish captured in 1989, one died, while eight died in 1990 during the sampling process. None died during the 1991 sampling process.

George Lake

Population abundance, length and age compositions, survival and recruitment were estimated in both 1990 and 1991. The sex composition of the northern pike population was not estimated in 1990, and was not a program objective in 1991.

Abundance:

There were an estimated 11,568 (SE = 1,277) northern pike over 299 mm in George Lake during May 1990 (Table 2). The estimated density was 6.3 fish per ha. This is considered a minimum estimate of abundance (and density) due to the mixing problems described below. During the first event, 1,283 unique northern pike were captured and released. After a two-day hiatus in sampling, 1,158 northern pike were captured and examined of which 127 (11%) were recaptures from the first event.

Prior to developing the 1990 estimate, several assumptions were tested. None of the recaptured fish had lost their tags, and the short interval between events assured population closure. Although the lake has an outlet, periodic observations indicate no northern pike enter or leave the lake. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike. Fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the three sampling areas (χ^2 = 0.559, df = 2, P > 0.05). Acceptance of this assumption is normally indicative of either complete mixing or uniform capture probabilities in either event. However, when the area of marked-fish release was compared (chi-squared test) with area of recapture, the result was significant (χ^2 < 0.001, df = 4, P < 0.05). This indicated that there was no mixing of marked and unmarked northern pike between events. In addition, a

Table 7. Estimated grouped-cohort survival rates of northern pike in Volkmar Lake, 1985-1991.

Sampling Year	Year Classes	Age Classes	Estimated Abundance	SE	Estimated Survival Rate	SE
1985 - 1986	1977-80	5-8	3,280 [a]	220	---	---
	1977-80	6-9	2,526	976	0.77	0.30
1986 - 1987	1978-81	5-8	3,545	1,334	---	---
	1978-81	6-9	1,751	399	0.49	0.09
1987 - 1988	1979-82	5-8	3,247	729	---	---
	1979-82	6-9	1,237	103	0.38	0.09
1988 - 1989	1980-83	5-8	2,009	142	---	---
	1980-83	6-9	759	139	0.38	0.07
1989 - 1990	1981-84	5-8	971	177	---	---
	1981-84	6-9	1,232	147	1.27	0.28
1990 - 1991	1982-85	5-8	1,761	188	---	---
	1982-85	6-9	1,360	184	0.77	0.13

[a] Includes only fish > 449 mm.

Table 8. Estimated annual recruitment of northern pike in Volkmar, T, and George lakes.

Recruitment Year	Volkmar Lake Recruitment (No. of Fish) Age	Estimate	SE	T Lake Recruitment (No. of Fish) Age	Estimate	SE	George Lake Recruitment (No. of Fish) Age	Estimate	SE
1985	5	1,238	137	---	---	---	---	---	---
1986	5	1,262	316	6	73	22	---	---	---
1987	5	1,611	284	6	125	22	4	5,390	697
1988	5	804	80	6	107	16	4	6,646	1,871
1989	5	263	52	6	36	11	4	7,232	1,033
1990	5	599	130	6	62	17	4	3,372	409
1991	5	479	81	6	49	11	4	3,406	340

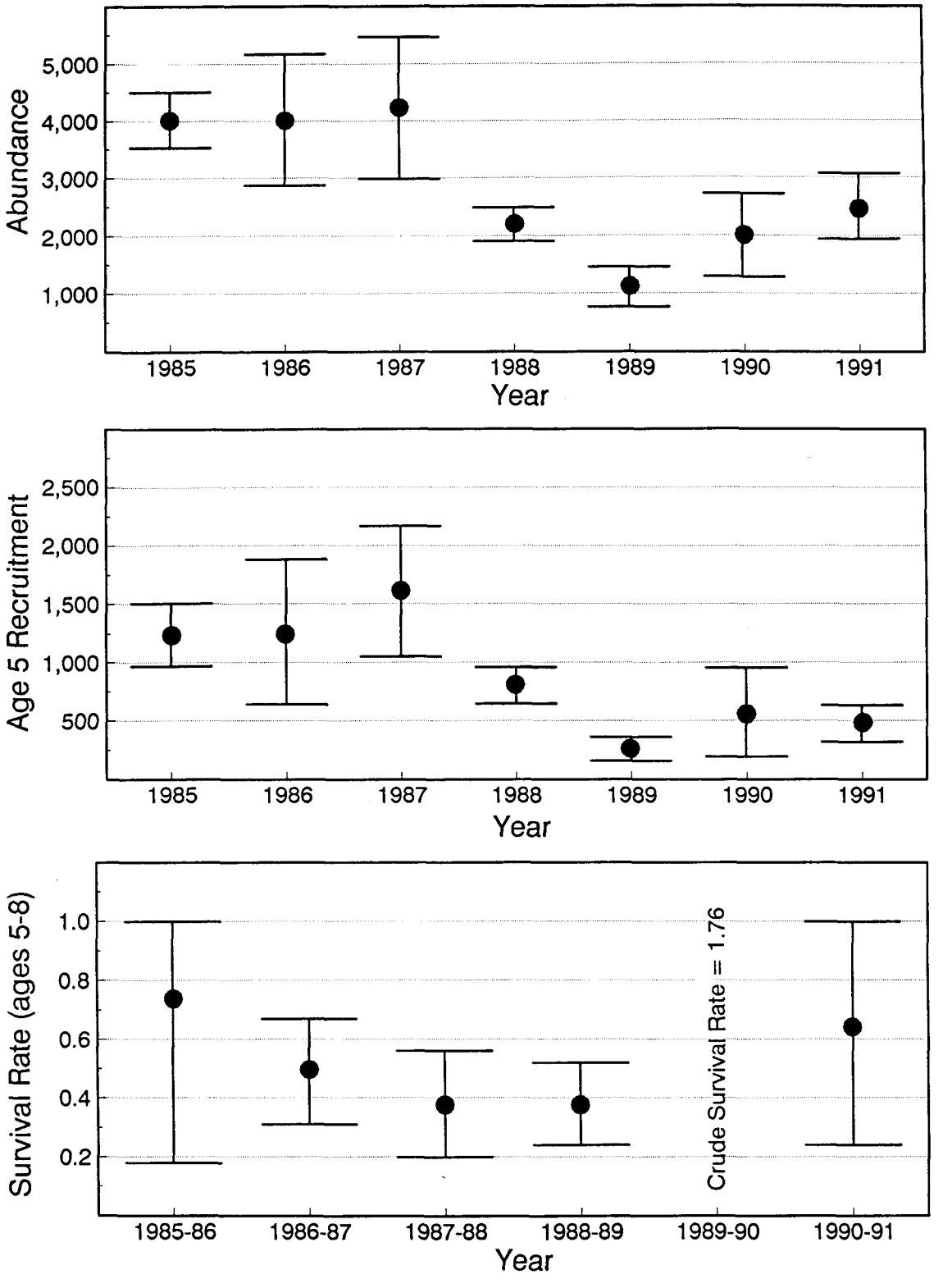

Figure 6. Estimates of abundance (fish > 449 mm FL), recruitment (age 5 fish), and survival rate (age 5-8 fish) for northern pike in Volkmar Lake 1985-1991 (bars reflect 95% confidence intervals; dots show point estimates).

low recapture rate of fish marked in Area 1 occurred (three of 143; 2%). Consequently, the estimate was stratified by area, with Areas 1 and 3 combined into one strata; Area 2 was used as the other strata. These problems with mixing rates between lake areas and the resultant stratification process qualify the estimate of abundance as a minimum value.

Comparison of the length distribution of fish marked during the first event with the length distribution of fish recaptured during the second event in 1990 showed that size-selectivity of the sampling gear during the second event was not significant (Kolmogorov-Smirnov two-sample test, $D = 0.08$, $n = 1,415$, $P = 0.397$). However, the length distribution of all fish captured during the second event was significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, $D = 0.17$, $n = 2,446$, $P = 0.001$), indicating size-selectivity of the gear occurred during the first event. Because of acceptance of the first size-dependent assumption, but failure of the second, one abundance estimate, unstratified by size but stratified by area, was calculated as per Appendix C, Case II.

Based upon the 1991 within-season mark recapture experiment, there were an estimated 15,944 (SE = 1,436) northern pike over 299 mm in George Lake during May 1991 (Table 2). The estimated density was 8.7/ha. Due to overlapping confidence intervals, abundance did not significantly change between 1990 and 1991. During the first event (Appendix A), 1,083 unique northern pike were captured and released. After a three-day hiatus in sampling, 1,514 northern pike were captured and examined, and of those, 102 (6.7%) were recaptures from the first event. During the first event in 1991, 406 (37%) northern pike were released in Area 1 (Figure 3), 171 (16%) were released in Area 2, and 506 (47%) were released in Area 3. During the second event, 606 (40%) fish were captured in Area 1, 460 (30%) were captured in Area 2, and 448 (30%) were captured in Area 3.

Several assumptions were tested prior to developing the 1991 estimate. An insignificant number (1; 0.1%) of the recaptured fish had lost their tags, and despite the presence of a lake outlet, the short interval between events assured population closure. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike; none of the northern pike handled during 1991 died during the sampling program. Since fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the three lake sampling areas ($\chi^2 = 0.143$, $df = 2$, $P > 0.05$), it was concluded that either marked fish mixed completely between events, or probabilities of capture during the first event were the same throughout the lake.

Comparison of the length distribution of fish marked during the first event with the length distribution of fish recaptured during the second event showed that size-selectivity of the sampling gear during the second event was not significant (Kolmogorov-Smirnov two-sample test, $D = 0.09$, $n = 1,185$, $P = 0.501$). However, the length distribution of all fish captured during the second event was significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, $D = 0.13$, $n = 2,597$, $P = < 0.001$). As this test is sample size dependent and overly sensitive to large sample sizes, and as the sample sizes were quite large (marks = 1,083;

captures = 1,514), the cumulative frequency by length plots of both groups were examined. Both plots (marks, captures) were essentially identical, indicating no apparent significant biological difference in lengths between the two groups of fish. As a result of these tests, an unstratified abundance estimate was developed as no size selectivity was detected in either sampling event, and a Case I (Appendix C) situation was indicated.

Composition:

Because of the assumption failures pertaining to the 1990 mark-recapture experiment described above, only the lengths, ages, and sexes from the second event were used to estimate proportions in composition during 1990 (Appendix C, Case II).

Fish in the medium size range predominated in 1990 (7,946; SE = 891), and again in 1991 (10,496, SE = 957; Table 2). The small category contributed 3,461 (SE = 412) northern pike to the overall population in 1990, and 5,005 (SE = 473) fish in 1991. There were few fish (161, SE = 43) in the large size group in 1990; more northern pike were estimated in this category in 1991 (443, SE = 65). Fish in the small category are mainly comprised of partially recruited northern pike. The abundance and proportion of northern pike in the medium and large categories were summed to estimate the number of fish over 449 mm. These fish consisted primarily of fish considered fully recruited to the spawning population (generally age 4 and above in George Lake), and numbered an estimated 8,107 (SE = 892) northern pike in 1990, and 10,939 (SE = 959) in 1991.

Estimated RSDs indicated northern pike in the stock category were most abundant in 1990 (7,172, SE = 808), and 1991 (9,252, SE = 847). Memorable and larger fish were almost absent in both years (Table 3).

In 1990, northern pike sampled demonstrated a strong mode between 425 and 600 mm (Table 9). Male northern pike sampled mostly ranged between 425 and 499 mm; few exceeded 649 mm. Female fish were most abundant between 525 and 824 mm in 1990; few captured were shorter than 450 mm. In 1991, northern pike sampled were most abundant between 500 and 524 mm (10.2%). Approximately 50% of the sampled northern pike were included in the 500 to 524 mm or smaller classes in 1990, and in the 475 to 499 mm or smaller length classes in 1991.

Northern pike of both sexes grew in length between successive ages (Table 10). In both years, females showed higher growth rates than males and were longer at age after age 2. Males were virtually absent in the samples after age 8.

The sex composition of the George Lake northern pike population was not estimated for 1990 or 1991. However, the composition of sampled fish (Table 10), indicates males comprised 10%, females 14%, and "sex unknown" fish 76% in 1990, and 16%, 30%, and 54%, respectively, in 1991.

In 1990, the age 4 and 5 cohorts predominated in proportion (29-28%), as well as in abundance (3,372 and 3,288; Table 11). Few northern pike (< 1%) sampled lived beyond 10 years (Figure 7). In 1991, the age 4 and 5 cohorts again predominated in both proportion (21 and 20%), as well as in abundance (3,406

Table 9. Length frequency of northern pike sampled in George Lake, 1987-1991.

Length Class (mm)	1987 Males No. of Fish	1987 Males Percent	1987 Females No. of Fish	1987 Females Percent	1987 All Fish No. of Fish	1987 All Fish Percent	1988 Males No. of Fish	1988 Males Percent	1988 Females No. of Fish	1988 Females Percent	1988 All Fish No. of Fish	1988 All Fish Percent
< 249	0	0.0	0	0.0	0	0.0	1	0.1	3	0.3	6	0.3
250 - 274	1	0.3	0	0.0	9	1.1	0	0.0	0	0.0	0	0.0
275 - 299	6	2.1	3	0.9	40	5.1	0	0.0	0	0.0	0	0.0
300 - 324	29	10.0	10	3.1	60	7.6	1	0.1	0	0.0	13	0.6
325 - 349	37	12.7	26	8.0	72	9.1	7	0.7	0	0.0	63	2.8
350 - 374	25	8.6	16	4.9	46	5.8	28	2.8	1	0.1	73	3.3
375 - 399	26	8.9	23	7.1	59	7.4	38	3.8	5	0.5	72	3.2
400 - 424	37	12.7	26	8.0	72	9.1	72	7.2	19	1.9	116	5.2
425 - 449	30	10.3	19	5.8	60	7.6	123	12.3	41	4.2	182	8.2
450 - 474	22	7.6	23	7.1	60	7.6	158	15.8	64	6.5	240	10.8
475 - 499	24	8.2	34	10.4	69	8.7	167	16.7	76	7.7	253	11.4
500 - 524	18	6.2	24	7.4	57	7.2	117	11.7	104	10.6	231	10.4
525 - 549	13	4.5	25	7.7	44	5.6	100	10.0	99	10.1	204	9.2
550 - 574	11	3.8	20	6.1	35	4.4	75	7.5	89	9.1	167	7.5
575 - 599	4	1.4	20	6.1	33	4.2	56	5.6	82	8.4	141	6.4
600 - 624	6	2.1	13	4.0	21	2.7	27	2.7	82	8.4	111	5.0
625 - 649	1	0.3	11	3.4	15	1.9	12	1.2	69	7.0	82	3.7
650 - 674	0	0.0	11	3.4	13	1.6	5	0.5	60	6.1	66	3.0
675 - 699	1	0.3	6	1.8	7	0.9	6	0.6	65	6.6	71	3.2
700 - 724	0	0.0	3	0.9	4	0.5	0	0.0	36	3.7	36	1.6
725 - 749	0	0.0	3	0.9	3	0.4	2	0.2	33	3.4	35	1.6
750 - 774	0	0.0	4	1.2	5	0.6	1	0.1	16	1.6	17	0.8
775 - 799	0	0.0	3	0.9	5	0.6	2	0.2	16	1.6	18	0.8
800 - 824	0	0.0	1	0.3	1	0.1	0	0.0	6	0.6	6	0.3
825 - 849	0	0.0	1	0.3	1	0.1	0	0.0	6	0.6	6	0.3
850 - 874	0	0.0	1	0.3	1	0.1	0	0.0	5	0.5	5	0.2
875 - 899	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	1	0.0
900 - 924	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	1	0.0
925 - 949	0	0.0	0	0.0	0	0.0	0	0.0	2	0.2	2	0.1
950 - 974	0	0.0	0	0.0	0	0.0	0	0.0	1	0.1	1	0.0
975 - 999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
>999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	291	100.0	998	100.0	326	100.0	982	100.0	792	100.0	2,219	100.0

-continued-

Table 9. (Page 2 of 3).

Length Class (mm)	1989 Males No. of Fish	1989 Males Percent	1989 Females No. of Fish	1989 Females Percent	1989 All Fish No. of Fish	1989 All Fish Percent	1990 Males No. of Fish	1990 Males Percent	1990 Females No. of Fish	1990 Females Percent	1990 All Fish No. of Fish	1990 All Fish Percent
< 249	3	0.4	3	0.2	6	0.2	0	0.0	1	0.3	6	0.3
250 - 274	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
275 - 299	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
300 - 324	0	0.0	1	0.1	15	0.6	0	0.0	0	0.0	4	0.2
325 - 349	5	0.6	6	0.5	51	2.1	1	0.4	1	0.3	35	1.5
350 - 374	13	1.6	5	0.4	74	3.0	3	1.3	0	0.0	30	1.3
375 - 399	26	3.3	10	0.8	94	3.9	11	4.7	0	0.0	49	2.1
400 - 424	51	6.4	28	2.2	122	5.0	15	6.5	0	0.0	80	3.4
425 - 449	69	8.7	39	3.1	157	6.5	38	16.4	2	0.6	172	7.2
450 - 474	112	14.1	67	5.3	209	8.6	44	19.0	4	1.3	243	10.2
475 - 499	118	14.9	73	15.8	219	9.0	38	16.4	7	2.2	242	10.2
500 - 524	102	12.9	101	8.0	225	9.2	19	8.2	9	2.9	226	9.5
525 - 549	109	13.7	125	9.9	249	10.2	18	7.8	13	4.1	211	8.9
550 - 574	80	10.1	124	9.8	213	8.8	14	6.0	10	3.2	199	8.4
575 - 599	46	5.8	154	12.2	205	8.4	13	5.6	26	8.3	206	8.7
600 - 624	36	4.5	139	11.0	177	7.3	7	3.0	33	10.5	174	7.3
625 - 649	11	1.4	107	8.5	121	5.0	5	2.2	34	10.8	119	5.0
650 - 674	8	1.0	77	6.1	88	3.6	2	0.9	35	11.1	117	4.9
675 - 699	0	0.0	54	4.3	55	2.3	2	0.9	36	11.4	101	4.2
700 - 724	1	0.1	51	4.0	52	2.1	0	0.0	25	7.9	53	2.2
725 - 749	1	0.1	27	2.1	28	1.2	2	0.9	28	8.9	39	1.6
750 - 774	1	0.1	24	1.9	25	1.0	0	0.0	18	5.7	25	1.1
775 - 799	1	0.1	13	1.0	14	0.6	0	0.0	12	3.8	21	0.9
800 - 824	0	0.0	13	1.0	13	0.5	0	0.0	11	3.5	15	0.6
825 - 849	0	0.0	13	1.0	13	0.5	0	0.0	3	1.0	5	0.2
850 - 874	0	0.0	2	0.2	2	0.5	0	0.0	2	0.6	2	0.1
875 - 899	0	0.0	6	0.5	6	0.1	0	0.0	2	0.6	2	0.1
900 - 924	0	0.0	1	0.1	1	0.2	0	0.0	3	1.0	3	0.1
925 - 949	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
950 - 974	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	1	0.0
975 - 999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
> 999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	793	100.0	1,263	100.0	2,434	100.0	232	100.0	315	100.0	2,380	100.0

-continued-

Table 9. (Page 3 of 3).

Length Class (mm)	1991 All Fish No. of Fish	Percent
< 249	7	0.3
250 - 274	0	0
275 - 299	0	0
300 - 324	76	2.9
325 - 349	126	4.9
350 - 374	141	5.4
375 - 399	118	4.5
400 - 424	139	5.4
425 - 449	213	8.2
450 - 474	212	8.2
475 - 499	213	8.2
500 - 524	265	10.2
525 - 549	211	8.1
550 - 574	183	7.0
575 - 599	140	5.4
600 - 624	146	5.6
625 - 649	82	3.2
650 - 674	79	3.0
675 - 699	78	3.0
700 - 724	50	1.9
725 - 749	46	1.8
750 - 774	34	1.3
775 - 799	23	0.9
800 - 824	6	0.2
825 - 849	3	0.1
850 - 874	2	0.1
875 - 899	3	0.1
900 - 924	0	0.0
925 - 949	1	0.0
950 - 974	0	0.0
975 - 999	0	0.0
> 999	0	0.0
Total	2,597	100.0

Table 10. Estimated mean length-at-age of northern pike (> 299 mm FL) sampled in George Lake, 1987-1991.

	1987			1988			1989		
		Fork Length (mm)			Fork Length (mm)			Fork Length (mm)	
Age	No. of Fish	Mean	SE	No. of Fish	Mean	SE	No. of Fish	Mean	SE
Males:									
2	5	392	15	3	347	12	1	307	---
3	97	397	5	107	412	3	18	421	5
4	117	448	5	135	451	3	56	439	3
5	68	496	7	48	494	8	43	470	3
6	34	544	9	31	524	8	21	501	5
7	13	557	19	23	563	10	13	532	6
8	9	614	17	4	623	25	3	544	13
9	2	607	30	---	---	---	---	---	---
10	---	---	---	1	651	---	---	---	---
11	1	676	---	1	670	---	---	---	---
12>	1	724	---	---	---	---	---	---	---
Total	347			353			155		
Females:									
2	3	320	8	1	357	---	1	317	18
3	45	412	10	41	427	5	25	413	4
4	74	489	7	106	482	4	56	468	3
5	90	531	8	89	536	5	65	529	3
6	60	604	9	95	572	8	34	571	4
7	37	663	11	50	636	6	30	612	5
8	30	725	14	22	652	9	14	643	7
9	35	734	12	11	722	10	10	719	8
10	23	770	16	11	705	16	1	766	28
11	1	709	---	5	750	24	2	806	20
12>	2	774	68	6	841	22	3	831	17
Total	400			437			241		
All Fish:									
2	17	342	10	56	327	3	13	324	2
3	164	403	5	174	408	3	84	384	3
4	212	465	4	251	462	3	140	444	5
5	184	518	5	139	520	5	118	500	5
6	103	578	7	126	564	5	62	542	5
7	55	632	11	73	613	7	43	588	7
8	42	695	13	26	648	9	17	625	11
9	43	703	16	12	715	12	10	718	19
10	23	770	16	12	700	15	1	766	23
11	2	693	12	6	737	23	2	806	48
12>	3	757	47	6	841	22	3	831	17
Total	848			881			493		

-continued-

Table 10. (Page 2 of 2).

Age	1990 No. of Fish	1990 Fork Length (mm) Mean	1990 Fork Length (mm) SE	1991 No. of Fish	1991 Fork Length (mm) Mean	1991 Fork Length (mm) SE	1987-91 Average No. of Fish	1987-91 Average Fork Length (mm) Mean	1987-91 Average Fork Length (mm) SE
Males:									
2	---	---	---	20	351	7	29	356	6
3	34	387	6	54	397	6	310	402	2
4	83	440	4	102	431	4	493	443	2
5	53	485	6	60	494	6	272	489	3
6	24	535	11	55	531	6	165	529	4
7	14	557	18	20	561	9	83	556	6
8	5	646	29	9	588	11	30	606	9
9	---	---	---	---	---	---	2	607	30
10	---	---	---	---	---	---	1	651	---
11	---	---	---	---	---	---	2	673	---
12>	---	---	---	---	---	---	1	724	---
Total	213			320			1,388		
Females:									
2	1	317	---	---	---	---	6	325	4
3	2	504	---	7	510	41	120	425	5
4	15	489	24	51	527	7	302	489	3
5	42	554	16	104	554	5	390	540	3
6	76	606	17	133	599	5	398	592	4
7	65	656	37	123	637	6	305	642	8
8	47	682	37	97	656	12	210	670	10
9	22	730	64	45	710	10	123	722	13
10	14	736	---	12	689	28	61	734	9
11	4	794	---	7	804	22	19	783	10
12>	5	839	17	4	712	98	20	807	22
Total	293			583			1,954		
All Fish:									
2	27	316	3	78	341	3	191	332	2
3	174	394	4	286	393	3	882	397	2
4	519	453	2	418	453	3	1,540	455	1
5	546	511	3	403	506	3	1,390	510	2
6	394	567	3	339	558	4	1,024	563	2
7	237	609	4	214	609	5	622	610	3
8	111	650	7	129	645	9	325	652	5
9	49	685	12	55	695	11	169	697	7
10	23	716	14	18	696	21	77	726	8
11	8	759	24	10	742	38	28	747	16
12>	8	838	21	7	759	61	27	808	19
Total	2,096			1,957			6,275		

Table 11. Estimated age composition and cohort abundance of the northern pike population (>299 mm FL) in George Lake, 1987-1991.

	1987[a]			1988			1989		
	No. of	Estimate		No. of	Estimate		No. of	Estimate	
Age	Fish	Proportion	Abundance SE	Fish	Proportion	Abundance SE	Fish	Proportion	Abundance SE
2		0.03	444 122	56	0.06	1,483 450	13	0.03	672 201
3		0.24	4,280 583	174	0.20	4,607 1,310	84	0.17	4,339 688
4		0.31	5,390 697	251	0.28	6,646 1,871	140	0.28	7,232 1,033
5		0.23	4,106 546	139	0.16	3,681 1,055	118	0.24	6,095 899
6		0.10	1,841 286	128	0.14	3,389 975	62	0.13	3,203 548
7		0.04	706 143	73	0.08	1,933 574	43	0.09	2,221 423
8		0.02	362 76	26	0.03	688 229	17	0.03	878 235
9		0.02	370 90	12	0.01	318 124	10	0.02	517 173
10		0.01	128 40	12	0.01	318 124	1	0.00	52 52
11		0.00	14 11	6	0.01	159 76	2	0.00	103 74
12>		0.00	21 13	6	0.01	159 68	3	0.01	154 90
Total			17,662 2,105	883		23,381 6,471	493		25,466 3,157

	1990			1991		
	No. of	Estimate		No. of	Estimate	
Age	Fish	Proportion	Abundance SE	Fish	Proportion	Abundance SE
2	16	0.02	193 52	78	0.04	635 91
3	99	0.10	1,197 174	286	0.15	2,330 245
4	279	0.29	3,372 409	418	0.21	3,406 340
5	272	0.28	3,288 400	403	0.21	3,283 329
6	154	0.16	1,862 247	339	0.17	2,762 283
7	80	0.08	967 148	214	0.11	1,744 193
8	32	0.03	387 79	129	0.06	1,051 130
9	15	0.02	181 50	55	0.03	448 72
10	6	0.01	73 30	18	0.01	147 37
11	2	0.00	24 17	10	0.01	81 27
12>	2	0.00	24 17	7	<0.01	57 22
Total	957		11,568 1,277	1,957	100	15,944 1,436

[a] Bootstrap samples (100) were drawn from age and length data from 847 fish sampled during 2-9 June 1987, and of length data from 721 fish sampled during 23-29 June 1987. Means and standard errors for each proportion were calculataed according to procedures in Efron (1982).

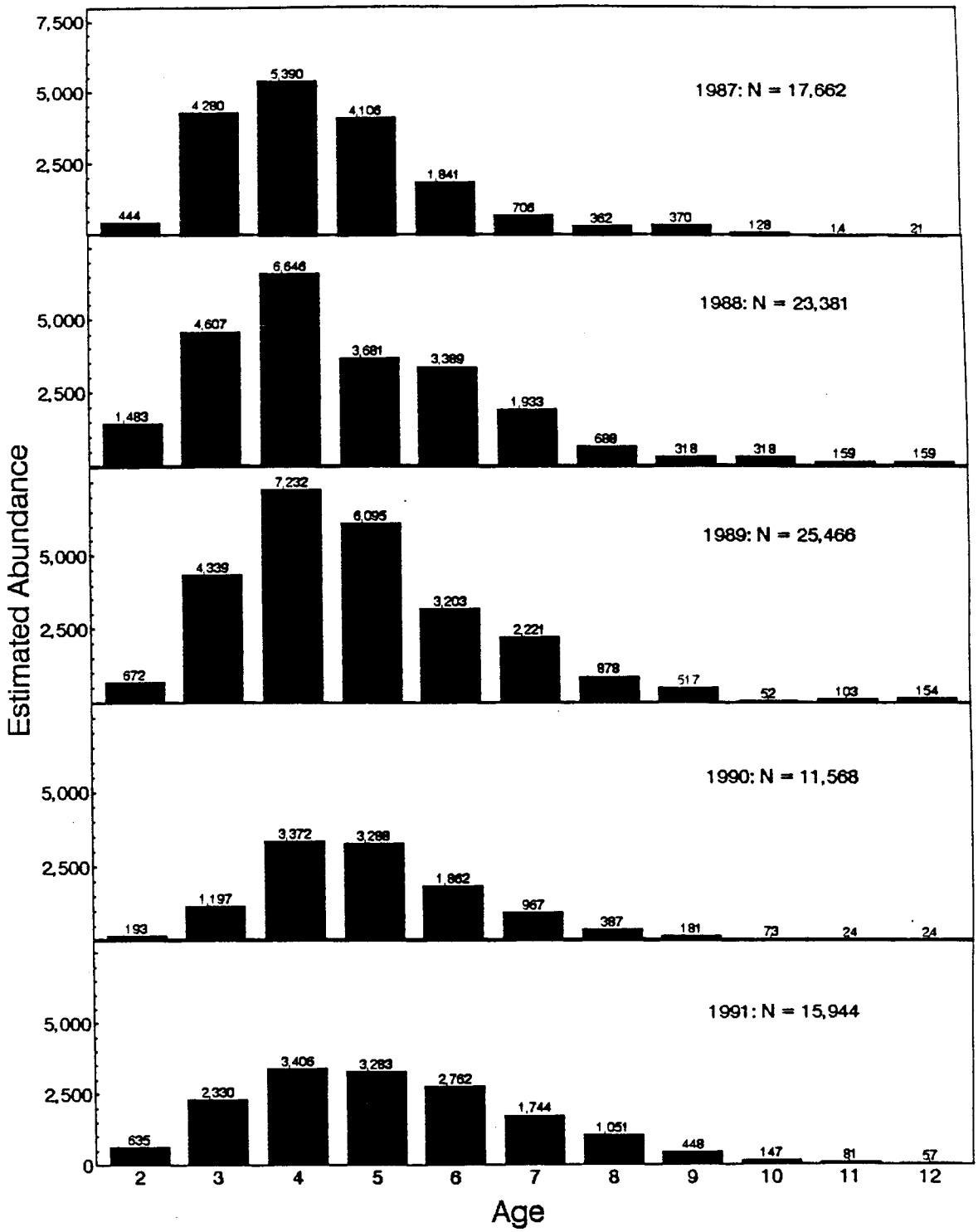

Figure 7. Estimated cohort abundance of the northern pike population (> 299 mm FL) in George Lake, 1987-1991.

and 3,283). The apparent increase in abundance of age 3 cohorts between 1990 and 1991 (1,197 to 2,330) is encouraging, as it likely indicates a favorable abundance of partially recruited northern pike to this population.

Survival and Recruitment

The ages selected for survival analysis, 4 to 7 in year y and 5 to 8 in year y+1, were chosen over older cohort-groups because the majority of sampled male northern pike appear to recruit to the sampling regime and spawning population as young as age 4 (Table 10), a year earlier than females, and few captured survive beyond age 8 (< 1% for the sampling years 1987-1991). About 35% (SE = 6) of the chosen cohorts survived between 1989 and 1990 (Table 12). Recruitment in 1990 of age 4 northern pike was estimated to be 3,372 fish (SE = 409) (Table 8). The mixing factors discussed earlier that contributed to the minimum abundance estimate also qualify the estimates of survival as a maximum value and recruitment as a minimum value. Survival between 1990 and 1991 was estimated to be 93% (SE = 13), and recruitment was estimated to be 3,406 (SE = 340; Figure 8). The minimum estimate of abundance in 1990 probably makes the estimated survival rate a maximum value between 1990 and 1991.

In 1990, 2,180 northern pike were tagged with blue tags in George Lake (Appendix B). Of fish captured, nine died in 1990 during the sampling process. In 1991, 1,679 northern pike were tagged with blue tags (Appendix B). The remainder of tagged fish handled in 1990 and 1991 were recaptures from prior events.

T Lake

The population abundance, length and age compositions, survival, and recruitment were estimated for 1989, 1990, and 1991. The sex composition of the northern pike population was not estimated in 1989 or 1990, and was not a program objective in 1991.

Abundance:

Two abundance estimates were calculated for the population of northern pike in T Lake as a result of the 1990 sampling effort. Due to catchability problems experienced during the entire 1989 sampling event, a within-season estimate of abundance was unavailable that year as only a single event was conducted (Pearse 1990). However, an estimate of abundance was calculated for 1989 using information collected during 1990 as the second event. The estimated abundance of northern pike over 299 mm in May 1989, corrected for growth recruitment, was 298 fish (SE = 31; Table 2). Density was estimated at 1.9 fish per ha. Tests for gear-selectivity between years proved negative (1989, 1990 Kolmogorov-Smirnov two-sample test, P = 0.081), as did the between year test for mixing (χ^2 = 0.409, df = 1, P > 0.05). In 1989, 88 unique northern pike were released. Of the 178 examined in 1990, four were recaptures from the 1989 event. Included in the 1990 sample of 178 northern pike, were fish that had recruited to the population through growth. The following values were used with Equations 3 and 4 to correct for growth recruitment between the 1989 mark and 1990 recapture events:

Table 12. Estimated grouped-cohort survival rates of northern pike in George Lake, 1987-1991.

Sampling Year	Year Classes	Age Classes	Estimated Abundance	SE	Survival Rate	Survival SE
1987 -	1980-83	4-7	12,043	1,462	---	---
1988	1980-83	5-8	9,691	2,708	0.80	0.25
1988 -	1981-84	4-7	15,649	4,346	---	---
1989	1981-84	5-8	12,397	1,639	0.79	0.24
1989 -	1982-85	4-7	18,751	2,378	---	---
1990	1982-85	5-8	6,504	741	0.35	0.06
1990 -	1983-86	4-7	9,489	1,057	---	---
1991	1983-86	5-8	8,840	816	0.93	0.13

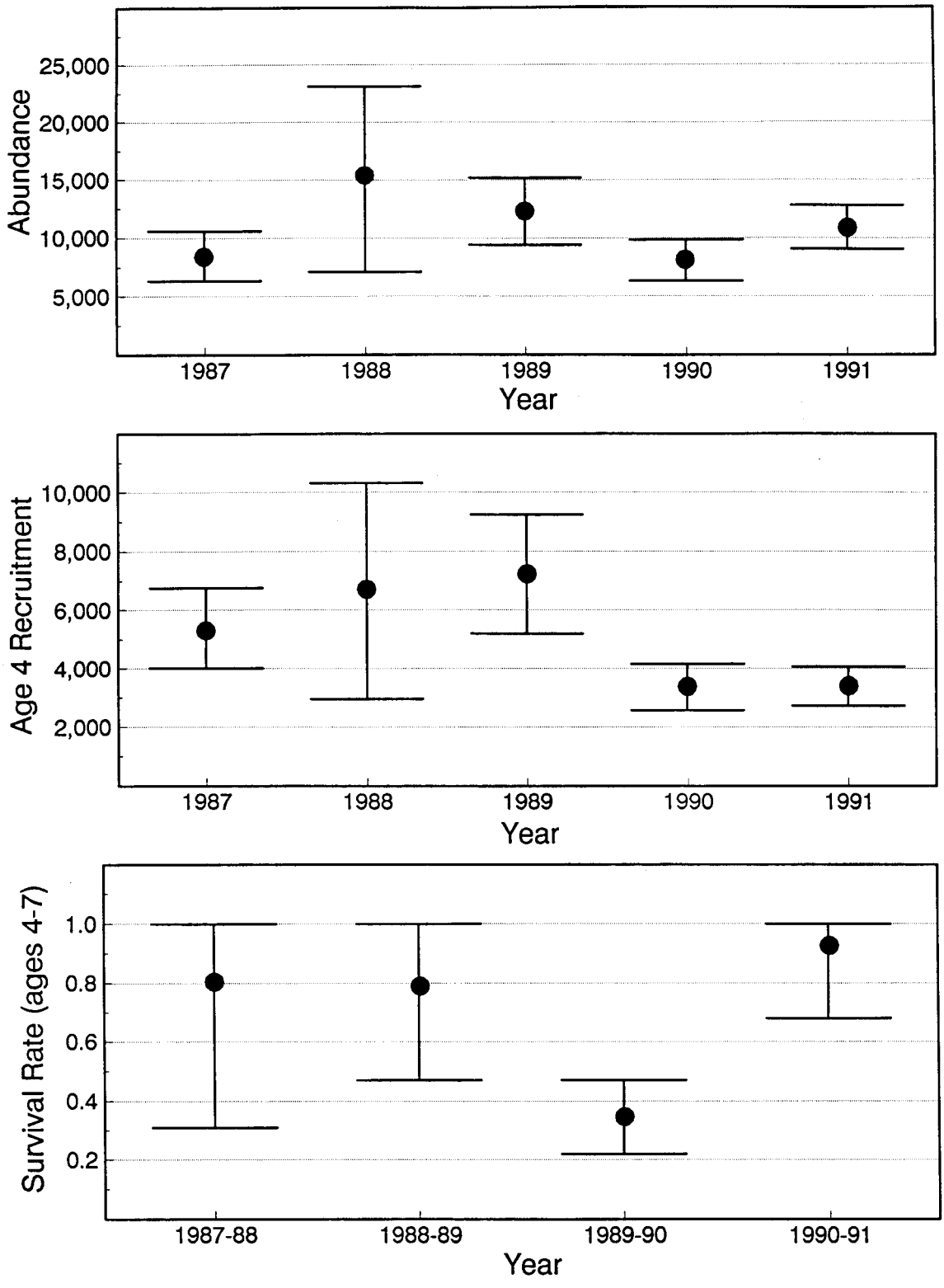

Figure 8. Estimates of abundance (fish > 449 mm FL), recruitment (age 4 fish), and survival rate (age 4-7 fish) for northern pike in George Lake 1987-1991 (bars reflect 95% confidence intervals; dots show point estimates).

$$\hat{N} = (88+1)\ (2.36 + 1) - 1;\ \text{and,}$$

$$\hat{V}[N] = (89+1)^2\ (0.12)$$

Based upon the 1990 within-season mark recapture experiment, there were an estimated 347 (SE = 42) northern pike over 299 mm FL in T Lake during May 1990 (Table 2). The estimated density was 2.2 fish per ha. During the first event (Appendix A), 101 unique northern pike were captured and released. After a two-day hiatus in sampling, 108 northern pike were captured and 31 were recaptures from the first event.

Prior to developing the 1990 abundance estimate, several assumptions were tested. None of the recaptured fish had lost their tags, and the short interval between events assured population closure. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike. Since fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the two sample areas ($\chi^2 = 0.126$, df = 1, $P > 0.05$), either marked fish mixed completely between events, or probabilities of capture during the first event were the same throughout the lake.

Comparison of the length distribution of fish marked during the first event with the length distribution of fish recaptured during the second event showed that size-selectivity of the gear during the second event was not significant (Kolmogorov-Smirnov two-sample test, D = 0.14, n = 133, P = 0.746). However, the length distribution of all fish captured during the second event was significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, D = 0.20, n = 214, P = 0.033), indicating size-selectivity in the gear did occur during the first event. Acceptance of the first test, but failure of the second test inferred that one unstratified abundance estimate be calculated (Appendix C, Case II)

Based upon the 1991 within-season mark recapture experiment, there were an estimated 328 (SE = 54) northern pike over 299 mm FL in T Lake during May 1991 (Table 2). The estimated density was 2.1 fish per ha. During the first event (Appendix A), 106 unique northern pike were captured and released (of which 43 were released in Area 1, and 63 were released in Area 2; Figure 3). After a two-day hiatus in sampling, 101 northern pike were captured (60 in Area 1 and 41 in Area 2). Of those captured, 31 were recaptures from the first event (17 were caught in Area 1, and 14 were caught in Area 2).

Several assumptions were tested prior to developing the 1991 abundance estimate. Only one (< 1%) of the recaptured fish had lost its tag, and the short interval between events assured population closure. Careful handling of the sampled fish prevented differential mortality between marked and unmarked northern pike (two fish died during the recapture event). Fractions of northern pike with marks captured during the second event (the R/C ratio) were not significantly different among the two sample areas ($\chi^2 = 0.325$, df = 1, $P > 0.05$). However, when the area of marked-fish release was compared with

area of recapture, the result was significant (χ^2 = 13.0, df = 1, P < 0.05). This indicated that there was no mixing of marked and unmarked northern pike between events. Consequently, the estimate was stratified by area, with Area 1 as one strata and Area 2 as the other strata.

Comparison of the length distribution of fish marked during the first event with the length distribution of fish recaptured during the second event showed that size-selectivity of the gear during the second event was not significant (Kolmogorov-Smirnov two-sample test, D = 0.19, n = 83, P = 0.828). Also, the length distribution of all fish captured during the second event was not significantly different than the length distribution from the first event (Kolmogorov-Smirnov two-sample test, D = 0.10, n = 151, P = 0.803), indicating size-selectivity in the gear did not occur during the first event. However, when the length distribution of Area 1 fish was compared with the length distribution of Area 2 fish, the result was significant (Kolmogorov-Smirnov two-sample test, D = 0.39, n = 151, P = < 0.001). This result indicated the composition estimate of the population should be stratified by area, and pooled after weighting the respective sampling compositions by the abundance estimate for each area.

Composition:

The data source for the 1989 composition estimates was all unique fish examined in 1989. Because of the assumption failure pertaining to the 1990 mark-recapture experiment described above, only the lengths and ages from the second event were used to estimate proportions of composition in 1990 (Appendix C, Case II). Correction for size bias was not required.

The estimated abundance of northern pike in the small size category (Table 2) was 27 (SE = 9) in 1989, 46 (SE = 12) in 1990, and 40 (SE = 9) in 1991. This category is mainly comprised of partially recruited northern pike. Fish in the medium size range predominated in all years. The proportion of fish in the large size category did not exceed 8% for these three years. The abundance and proportion of northern pike in the medium and large categories were summed to estimate all fish over 449 mm, and numbered 271 (SE = 27) in 1989, 301 (SE = 38) in 1990, and 288 (SE = 33) in 1991. This group consisted primarily of fish of both sexes that were fully recruited to the spawning population (age 6 and above in T Lake). In T Lake, male northern pike are generally absent from the large size category (> 749 mm, Table 13); the proportion and abundance of large size fish (sexes combined) appeared to remain stable between 1989 and 1991.

Estimated RSDs changed little between 1989 and 1991 (Table 3), with northern pike in the quality category being most abundant in all years. Memorable and trophy fish were essentially absent.

Length frequencies of all fish sampled peaked between 525 and 675 mm, (Table 13). In 1990, all northern pike sampled demonstrated a strong mode between 575 and 600 mm, and in 1991, between 550 and 674 mm. Length frequencies of male northern pike sampled in 1989 showed peaks between 525 and 550 mm, and again between 600 and 625 mm, few less than 475 mm were captured, and none exceeded 875 mm (Table 13). In 1990, male northern pike were grouped in

Table 13. Length frequency of northern pike sampled in T Lake, 1986-1991.

Length Class (mm)	1986 Males No. of Fish	1986 Males Percent	1986 Females No. of Fish	1986 Females Percent	1986 All Fish No. of Fish	1986 All Fish Percent	1987 Males No. of Fish	1987 Males Percent	1987 Females No. of Fish	1987 Females Percent	1987 All Fish No. of Fish	1987 All Fish Percent
< 249	0	0.0	0	0.0	1	0.3	0	0.0	0	0.0	6	1.9
250 - 274	0	0.0	0	0.0	1	0.3	0	0.0	0	0.0	0	0.0
275 - 299	0	0.0	0	0.0	2	0.5	0	0.0	0	0.0	0	0.0
300 - 324	1	0.7	0	0.0	3	0.8	4	4.3	0	0.0	10	3.2
325 - 349	4	3.0	0	0.0	6	1.6	7	7.6	4	2.4	12	3.8
350 - 374	2	1.5	0	0.0	4	1.0	4	4.3	0	0.0	7	2.2
375 - 399	1	0.7	0	0.0	3	0.8	2	2.2	1	0.6	4	1.3
400 - 424	6	4.4	0	0.0	7	1.8	5	5.4	1	0.6	8	2.6
425 - 449	5	3.7	2	1.2	9	2.4	2	2.2	4	2.4	8	2.6
450 - 474	4	3.0	0	0.0	6	1.6	8	8.7	5	3.0	15	4.8
475 - 499	3	2.2	3	1.7	11	2.9	16	17.4	7	4.1	25	8.0
500 - 524	5	3.7	3	1.7	10	2.6	12	13.0	8	4.7	21	6.7
525 - 549	9	6.7	4	2.3	17	4.5	7	7.6	6	3.6	16	5.1
550 - 574	12	8.9	7	4.1	21	5.5	3	3.3	7	4.1	12	3.8
575 - 599	16	11.9	12	7.0	28	7.3	6	6.5	9	5.3	19	6.1
600 - 624	22	16.3	12	7.0	40	10.5	7	7.6	6	3.6	13	4.2
625 - 649	21	15.6	11	6.4	43	11.3	3	3.3	10	5.9	15	4.8
650 - 674	15	11.1	24	14.0	42	11.0	2	2.2	14	8.3	17	5.4
675 - 699	3	2.2	20	11.6	26	6.8	1	1.1	19	11.2	24	7.7
700 - 724	3	2.2	16	9.3	24	6.3	3	3.3	15	8.9	21	6.7
725 - 749	3	2.2	20	11.6	30	7.9	0	0.0	15	8.9	16	5.1
750 - 774	0	0.0	13	7.6	17	4.5	0	0.0	9	5.3	10	3.2
775 - 799	0	0.0	9	5.2	11	2.9	0	0.0	5	3.0	7	2.2
800 - 824	0	0.0	4	2.3	7	1.8	0	0.0	10	5.9	11	3.5
825 - 849	0	0.0	5	2.9	5	1.3	0	0.0	4	2.4	5	1.6
850 - 874	0	0.0	2	1.2	2	0.5	0	0.0	3	1.8	4	1.3
875 - 899	0	0.0	3	1.7	3	0.8	0	0.0	3	1.8	3	1.0
900 - 924	0	0.0	1	1.6	1	0.3	0	0.0	1	0.6	1	0.3
925 - 949	0	0.0	0	0.0	0	0.0	0	0.0	2	1.2	2	0.6
950 - 974	0	0.0	0	0.0	0	0.0	0	0.0	1	0.6	1	0.3
975 - 999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1,000-1,024	0	0.0	1	0.6	1	0.3	0	0.0	0	0.0	0	0.0
> 1,024	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	135	100.0	172	100.0	381	100.0	92	100.0	169	100.0	313	100.0

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Table 13. (Page 2 of 3).

Length Class (mm)	1988 Males No. of Fish	1988 Males Percent	1988 Females No. of Fish	1988 Females Percent	1988 All Fish No. of Fish	1988 All Fish Percent	1989 Males No. of Fish	1989 Males Percent	1989 Females No. of Fish	1989 Females Percent	1989 All Fish No. of Fish	1989 All Fish Percent
< 249	0	0.0	0	0.0	45	15.1	0	0.0	0	0.0	0	0.0
250 - 274	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
275 - 299	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
300 - 324	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
325 - 349	6	4.7	0	0.0	7	2.3	0	0.0	0	0.0	3	3.3
350 - 374	8	6.2	0	0.0	8	2.7	2	5.4	0	0.0	3	3.3
375 - 399	5	3.9	0	0.0	5	1.7	0	0.0	0	0.0	1	1.1
400 - 424	3	2.3	0	0.0	4	1.3	0	0.0	0	0.0	1	1.1
425 - 449	5	3.9	2	1.8	7	2.3	0	0.0	0	0.0	0	0.0
450 - 474	8	6.2	2	1.8	12	4.0	0	0.0	0	0.0	1	1.1
475 - 499	8	6.2	4	3.5	13	4.3	2	5.4	0	0.0	4	4.4
500 - 524	14	10.9	1	0.9	16	5.4	2	5.4	0	0.0	5	5.6
525 - 549	16	12.4	6	5.3	22	7.4	4	10.8	4	14.3	10	11.1
550 - 574	17	13.2	6	5.3	23	7.7	6	16.2	0	0.0	12	13.3
575 - 599	8	6.2	12	10.6	22	7.4	2	5.4	2	7.1	6	6.7
600 - 624	9	7.0	7	6.2	16	5.4	4	10.8	4	14.3	9	10.0
625 - 649	6	4.7	9	8.0	16	5.4	9	24.3	0	0.0	10	11.1
650 - 674	6	4.7	6	5.3	13	4.3	2	5.4	7	25.0	9	10.0
675 - 699	6	4.7	9	8.0	16	5.4	1	2.7	0	0.0	1	1.1
700 - 724	2	1.6	14	12.4	17	5.7	0	0.0	2	7.1	2	2.2
725 - 749	1	0.8	10	8.8	11	3.7	1	2.7	2	7.1	3	3.3
750 - 774	1	0.8	6	5.3	6	2.0	0	0.0	2	7.1	3	3.3
775 - 799	0	0.0	3	2.7	3	1.0	0	0.0	0	0.0	0	0.0
800 - 824	0	0.0	3	2.7	3	1.0	0	0.0	2	7.1	2	2.2
825 - 849	0	0.0	1	0.9	2	0.7	1	2.7	1	3.6	2	2.2
850 - 874	0	0.0	5	4.4	5	1.7	1	2.7	1	3.6	2	2.2
875 - 899	0	0.0	3	2.7	3	1.0	0	0.0	0	0.0	0	0.0
900 - 924	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
925 - 949	0	0.0	3	2.7	3	1.0	0	0.0	1	3.6	1	0.0
950 - 974	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	1.1
975 - 999	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
1,000-1,024	0	0.0	1	0.9	1	0.3	0	0.0	0	0.0	0	0.0
> 1,024	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0
Total	129	100.0	113	100.0	299	100.0	37	100.0	28	100.0	90	100.0

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Table 13. (Page 3 of 3).

Length Class (mm)	1990 Males No. of Fish	1990 Males Percent	1990 Females No. of Fish	1990 Females Percent	1990 All Fish No. of Fish	1990 All Fish Percent	1991 All Fish No. of Fish	1991 All Fish Percent
< 249	0	0.0	1	1.3	1	0.5	1	0.7
250 - 274	0	0.0	0	0.0	0	0.0	0	0
275 - 299	0	0.0	0	0.0	0	0.0	2	1.3
300 - 324	0	0.0	0	0.0	2	1.0	4	2.6
325 - 349	2	2.4	0	0.0	3	1.4	5	3.3
350 - 374	0	0.0	0	0.0	1	0.5	2	1.3
375 - 399	3	3.6	0	0.0	3	1.4	0	0
400 - 424	1	1.2	1	1.3	4	1.9	5	3.3
425 - 449	1	1.2	0	0.0	4	1.9	3	2.0
450 - 474	7	8.4	0	0.0	11	5.3	9	6.0
475 - 499	5	6.0	3	3.9	13	6.3	6	4.0
500 - 524	5	6.0	1	1.3	6	2.9	10	6.6
525 - 549	4	4.8	2	2.6	6	2.9	5	3.3
550 - 574	9	10.8	2	2.6	13	6.3	21	13.9
575 - 599	22	26.5	7	9.2	35	16.9	7	4.6
600 - 624	13	15.7	8	10.5	30	14.5	6	4.0
625 - 649	4	4.8	5	6.6	14	6.8	19	12.6
650 - 674	0	0.0	9	11.8	11	5.3	13	8.6
675 - 699	1	1.2	11	14.5	14	6.8	10	6.6
700 - 724	2	2.4	7	9.2	11	5.3	7	4.6
725 - 749	1	1.2	4	5.3	6	2.9	3	2.0
750 - 774	1	1.2	3	3.9	5	2.4	3	2.0
775 - 799	0	0.0	4	5.3	4	1.9	1	0.7
800 - 824	0	0.0	3	3.9	3	1.4	5	3.3
825 - 849	1	1.2	1	1.3	2	1.0	2	1.3
850 - 874	1	1.2	2	2.6	3	1.4	2	1.3
875 - 899	0	0.0	1	1.3	1	0.5	0	0.0
900 - 924	0	0.0	0	0.0	0	0.0	0	0.0
925 - 949	0	0.0	0	0.0	0	0.0	0	0.0
950 - 974	0	0.0	0	0.0	0	0.0	0	0.0
975 - 999	0	0.0	1	1.3	1	0.5	0	0.0
1,000-1,024	0	0.0	0	0.0	0	0.0	0	0.0
> 1,024	0	0.0	0	0.0	0	0.0	0	0.0
Total	83	100.0	76	100.0	207	100.0	151	100.0

length between 550 and 600 mm, few were less than 450 or greater than 650 mm. Female fish were loosely aggregated between 525 and 750 mm in 1989 (Table 13), few captured were less than 525 or greater than 775 mm. In 1990, female northern pike were most abundant between 575 and 700 mm, with few sampled shorter than 475 or longer than 825 mm FL. Approximately 50% of the sampled northern pike (all fish category) were included in the 575 to 599 mm or smaller length classes in 1989, 1990, and 1991.

The sex composition of the T Lake northern pike population was not estimated for either 1989 or 1990. However, the composition of sampled fish (Table 14), indicated males comprised 40%, females comprised 37%, and "sex unknown" fish comprised 23% in 1989. In 1990, the proportions of sampled northern pike were 16% male, 16% female, and 68% "sex unknown" respectively. In 1991, the respective proportions were 39% male, 40% female, and 21% "sex unknown".

Northern pike of both sexes grew between successive ages, except for ages 6 and 7 (sexes combined) in both 1990 and 1991 (Table 14). In both years, females showed higher growth rates than males and were longer at age after age 2. Few male northern pike captured lived longer than age 10.

In 1989, the age 7 and 8 cohorts shared almost equally in abundance (61 and 65) for sex-combined data (Table 15). In 1990, the age 6 to age 8 cohorts predominated almost equally in abundance (62, 62, and 70 respectively), while in 1991, the age 7 and age 8 cohorts were the most abundant (56 and 82, respectively; Figure 9).

Survival and Recruitment:

The ages selected for survival analysis, 6 to 9 in year y and 7 to 10 in year y+1, were chosen over older cohort-groups because the majority of male northern pike appear to recruit to our sampling program and spawning population at age 6, a year earlier than females, and few survive beyond age 10. Although this sex-dependent cohort data is not available for all years, it contributed to the choice of what cohort-groups to select for analysis. As shown, 58% (SE = 10) of the chosen cohorts are estimated to have survived between 1988 and 1989 (Table 16). Recruitment in 1989 (Table 8) of age 6 northern pike was 36 fish (SE = 11). The estimated survival between 1989 and 1990 was 84% (SE = 18). Recruitment in 1990 was estimated at 62 fish (SE = 17). The estimated survival between 1990 and 1991 was 79% (SE = 18). Recruitment in 1991 was estimated at 49 fish (SE = 11) northern pike (Figure 10).

In 1989, 27 northern pike were tagged with green Floy tags, in 1990, 83 were tagged with blue tags, and in 1991, 54 northern pike were tagged with blue tags in T Lake (Appendix B). The remainder of tagged fish handled in these years were recaptures from prior events. Of all fish captured, none died in 1990 and two died in 1991.

Table 14. Estimated length-at-age of northern pike (> 299 mm FL) in T Lake, 1986-1991.

	1986			1987			1988			1989		
		Fork Length (mm)			Fork Length (mm)			Fork Length (mm)			Fork Length (mm)	
Age	No. of Fish	Mean	SE	No. of Fish	Mean	SE	No. of Fish	Mean	SE	No. of Fish	Mean	SE
Males:												
2	---	---	---	1	303	---	---	---	---	---	---	---
3	3	340	6	7	307	6	6	336	8	6	334	9
4	4	387	37	10	395	18	12	361	17	13	439	10
5	5	495	51	20	436	14	23	445	19	6	497	13
6	5	577	31	19	488	10	32	513	10	11	511	12
7	5	604	30	8	551	20	27	528	12	21	551	7
8	6	675	25	7	582	19	12	579	13	23	578	7
9	1	621	---	2	616	22	6	643	24	13	596	8
10	1	747	---	4	613	49	3	589	41	2	635	45
11	---	---	---	---	---	---	3	667	4	3	751	29
12>	---	---	---	---	---	---	1	820	---	3	807	5
Total	30			78			125			101		
Females:												
2	---	---	---	---	---	---	---	---	---	---	---	---
3	---	---	---	2	314	9	---	---	---	---	---	---
4	---	---	---	4	405	38	1	304	---	2	469	4
5	2	511	63	12	530	34	5	529	44	4	522	20
6	5	613	28	23	548	14	21	565	15	12	591	24
7	5	683	22	20	617	15	24	620	15	17	553	39
8	7	730	14	20	654	18	26	658	14	24	633	11
9	7	773	22	23	672	17	9	734	37	19	689	12
10	4	821	36	22	748	16	14	688	60	7	735	36
11	2	752	22	4	767	27	4	777	35	3	783	30
12>	---	---	---	8	862	34	9	837	31	5	835	20
Total	32			138			113			93		
All Fish:												
2	---	---	---	3	289	6	1	252	4	2	302	2
3	3	340	6	14	337	4	7	327	13	13	343	11
4	4	387	37	23	430	6	15	365	13	22	439	7
5	7	500	38	35	524	5	29	455	6	19	497	11
6	10	595	20	53	596	5	57	532	6	31	551	13
7	10	643	22	36	607	9	54	573	9	48	550	14
8	13	706	15	35	643	10	40	632	15	59	604	7
9	8	751	28	31	704	24	15	698	29	35	653	11
10	5	806	31	27	729	28	17	672	29	9	713	32
11	2	752	22	6	805	63	7	730	60	6	767	20
12>	---	---	---	4	842	86	10	821	28	8	824	18
Total	62			267			252			252		

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Table 14. (Page 2 of 2).

Age	1990 No. of Fish	1990 Fork Length (mm) Mean	1990 Fork Length (mm) SE	1991 No. of Fish	1991 Fork Length (mm) Mean	1991 Fork Length (mm) SE	1986-91 Average No. of Fish	1986-91 Average Fork Length (mm) Mean	1986-91 Average Fork Length (mm) SE
Males:									
2	---	---	---	---	---	---	1	303	---
3	3	340	1	4	332	14	26	328	4
4	4	430	1	9	437	14	48	409	7
5	3	474	---	5	496	16	57	453	9
6	5	509	1	7	509	12	74	506	6
7	6	553	---	8	552	7	70	542	6
8	4	564	1	14	580	9	60	578	5
9	2	590	---	3	595	10	26	608	7
10	---	---	---	---	---	---	9	610	28
11	---	---	---	1	720	---	7	711	13
12>	---	---	---	2	787	---	6	803	3
Total	27			53			384		
Females:									
2	---	---	---	---	---	---	---	---	---
3	---	---	---	---	---	---	2	314	9
4	1	465	---	2	468	4	10	426	15
5	1	559	---	4	522	20	26	528	18
6	5	540	17	8	594	34	69	565	9
7	6	609	25	11	537	59	78	592	13
8	7	630	22	13	638	14	90	645	7
9	5	694	26	11	683	18	67	689	9
10	1	663	---	4	761	41	48	728	20
11	---	---	---	1	834	---	12	780	17
12>	1	826	---	1	826	---	24	844	17
Total	27			55			426		
All Fish:									
2	3	281	14	1	300	---	10	287	5
3	9	350	15	9	350	16	52	342	5
4	19	441	7	15	441	9	94	426	4
5	12	496	11	12	496	11	107	494	3
6	21	561	17	19	555	18	181	560	4
7	31	558	21	23	551	28	192	569	7
8	41	606	8	34	608	9	209	617	4
9	23	662	14	15	668	17	119	676	9
10	7	732	36	4	761	41	64	714	16
11	2	777	57	2	777	57	23	767	26
12>	3	800	---	3	800	---	28	820	17
Total	171			137			1,079		

Table 15. Estimated age composition and cohort abundance of the northern pike population (> 299 mm FL) in T Lake, 1986-1991.

	1986				1987				1988			
	No. of	Estimated[a]			No. of	Estimated			No. of	Estimated		
Age	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE	Fish	Proportion	Abundance	SE
2	---	----	---	---	1	<.01	3	3	1	<.01	2	2
3	3	0.05	22	13	9	0.04	26	9	7	0.03	13	5
4	4	0.06	29	14	14	0.07	41	12	15	0.06	28	7
5	7	0.11	51	19	32	0.15	94	19	29	0.11	51	11
6	10	0.16	73	22	42	0.20	125	22	57	0.23	107	16
7	10	0.16	73	22	28	0.13	82	17	54	0.21	97	15
8	13	0.21	95	25	27	0.13	79	17	40	0.16	74	13
9	8	0.13	59	20	25	0.12	73	16	15	0.06	28	7
10	5	0.08	37	16	26	0.12	76	16	12	0.07	33	8
11	2	0.03	15	10	4	0.02	12	6	6	0.03	14	5
12	---	---	---	---	4	0.02	12	6	6	0.04	18	6
Total	62	1.00	454	37	212	1.00	623	70	242	1.00	465	43

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Table 15. (Page 2 of 2).

Age	1989				1990				1991			
	No. of Fish	Estimated Proportion	Abundance	SE	No. of Fish	Estimated Proportion	Abundance	SE	No. of Fish	Estimated Proportion	Abundance	SE
2	1	0.01	4	4	3	0.04	15	8	1	0.01	3	3
3	4	0.05	14	7	6	0.08	28	11	9	0.06	21	7
4	3	0.04	11	6	8	0.11	38	13	15	0.11	36	10
5	7	0.08	25	9	6	0.08	28	11	12	0.09	28	19
6	10	0.12	36	11	14	0.18	62	17	19	0.13	44	11
7	17	0.20	61	15	14	0.18	62	17	23	0.17	56	12
8	18	0.22	65	15	15	0.20	70	18	34	0.25	82	15
9	12	0.14	43	12	8	0.11	38	13	15	0.11	35	10
10	2	0.02	7	5	1	0.01	3	5	4	0.03	10	5
11	4	0.05	14	7	---	---	---	---	2	0.02	5	4
12>	5	0.06	18	8	1	0.01	3	5	3	0.02	8	5
Total	83	1.00	298	31	76	1.00	347	42	137	1.00	328	54

[a] Includes fish > 449 mm only.

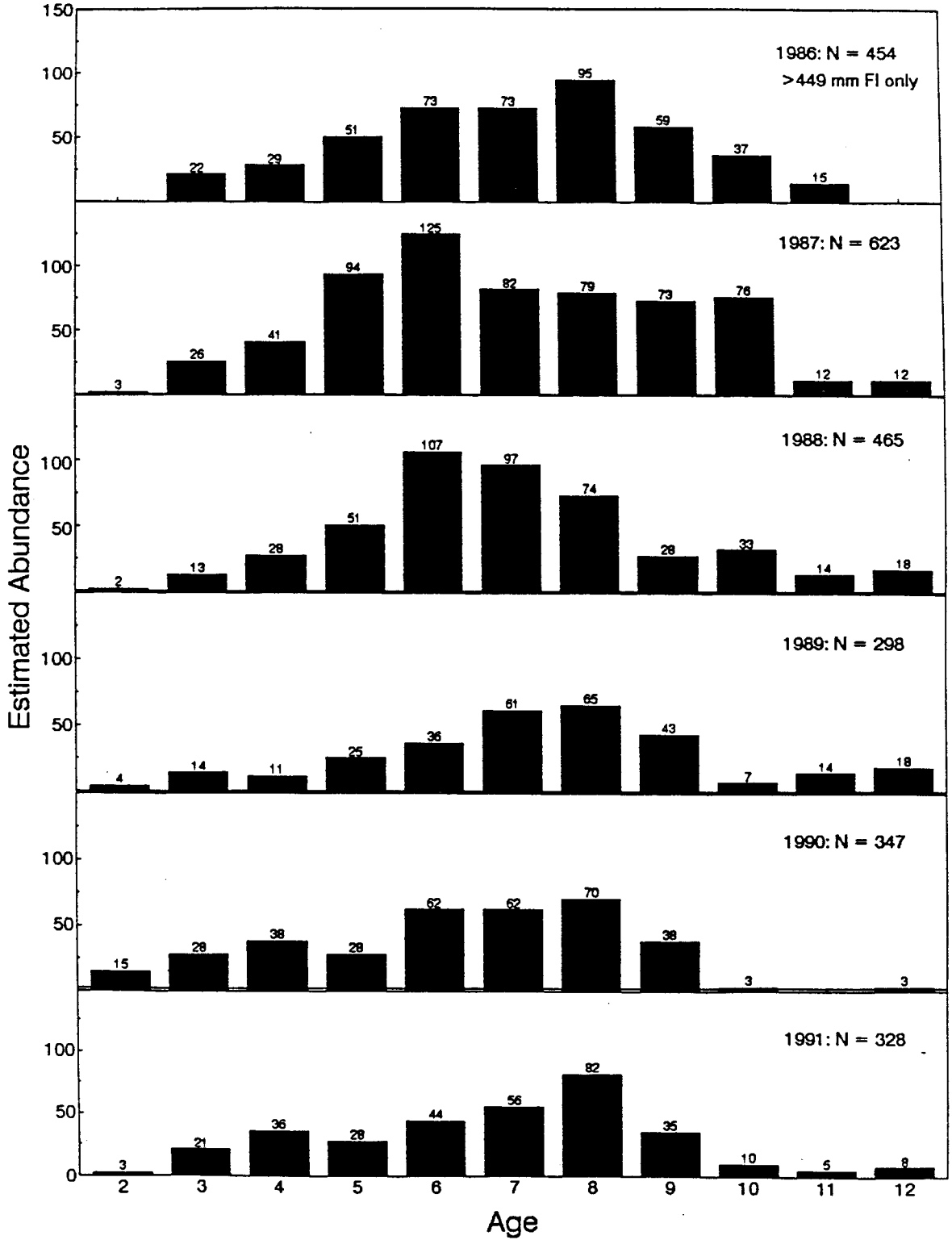

Figure 9. Estimated cohort abundance of the northern pike population (> 299 mm FL) n T Lake, 1986-1991.

Table 16. Estimated grouped-cohort survival rates in T Lake, 1986 - 1991.

Sampling Year	Year Classes	Age Classes	Estimated Abundance	SE	Estimated Survival Rate	SE
1986 -	1977-80	6-9	300 [a]	37	---	---
1987	1977-80	7-10	312	41	1.03	0.19
1987 -	1978-81	6-9	359	46	---	---
1988	1978-81	7-10	232	26	0.65	0.11
1988 -	1979-82	6-9	306	32	---	---
1989	1979-82	7-10	176	24	0.58	0.10
1989 -	1980-83	6-9	205	26	---	---
1990	1980-83	7-10	173	29	0.84	0.18
1990 -	1983-86	6-9	232	34	---	---
1991	1983-86	7-10	183	33	0.79	0.18

[a] Includes only fish > 449 mm.

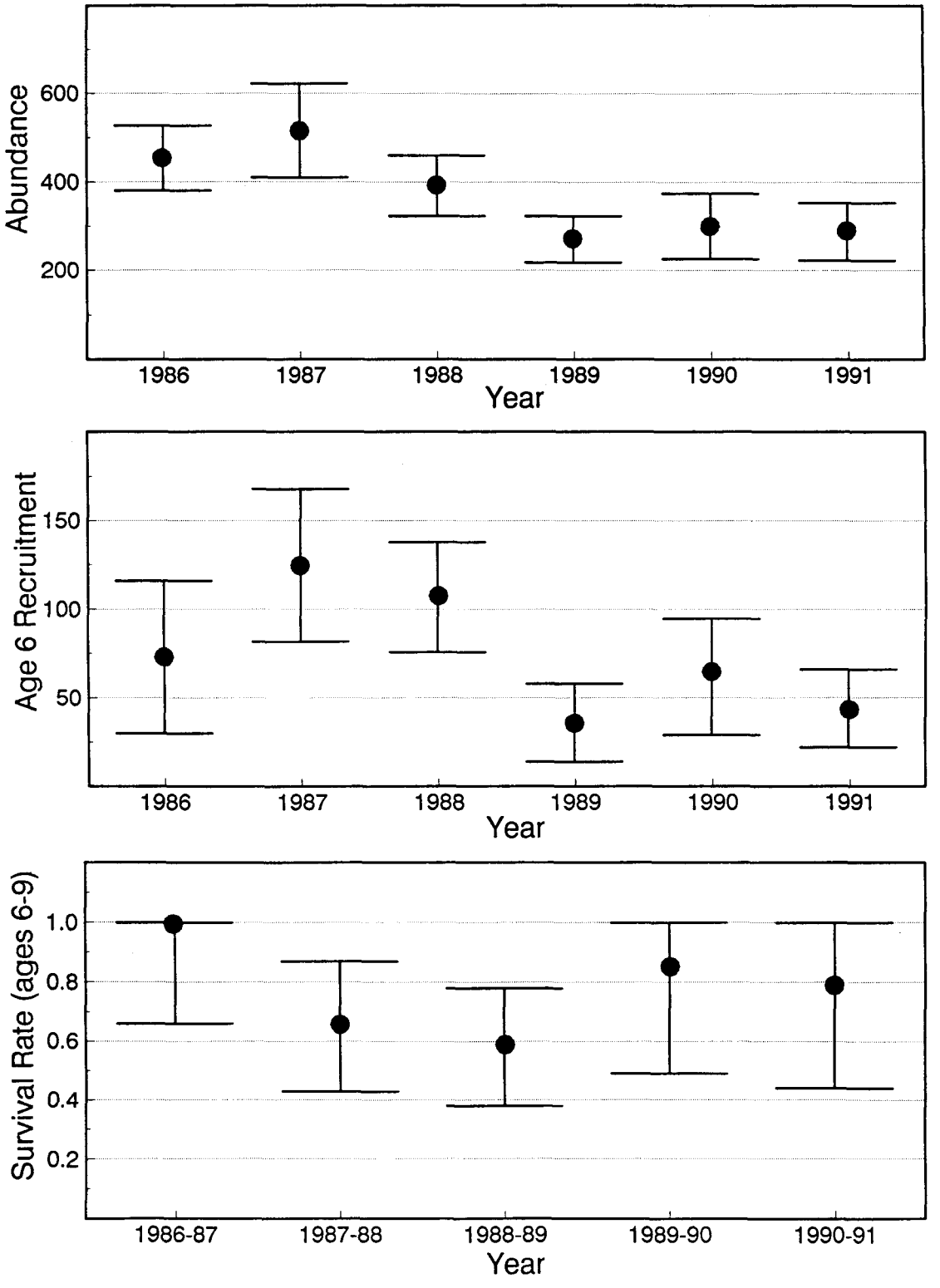

Figure 10. Estimates of abundance (fish > 449 mm FL), recruitment (age 6 fish), and survival rate (age 6-9 fish) for northern pike in T Lake 1986-1991 (bars reflect 95% confidence intervals; dots show point estimate).

DISCUSSION

Volkmar Lake

The abundance of northern pike over 299 mm in Volkmar Lake significantly declined between 1986 and 1989. In 1991 the abundance was significantly greater compared to that in 1989. The reasons for these fluctuations in abundance are unknown, but may be due to such factors as harvest, survival, and/or recruitment. Fishery statistics and characteristics were examined to see if any causative trends between population abundance and harvest could be observed. There is little correlation between abundance and harvest per angler day in the years 1986 to 1989. However, the estimated harvest apparently declined with declining abundance (variance estimates of harvest are lacking). The average estimated harvest density (1.7 fish per ha) is higher for Volkmar Lake than for George (1/ha) and T (0.9/ha) lakes, but is occasionally lower for certain years. This seems reasonable because Volkmar Lake has a higher density of northern pike than George and T lakes for most of the years studied (1985 to 1991). For the years 1986 to 1989, the last year for which an estimate of harvest is available, estimated exploitation rates would have ranged from 3 to 14% (9% average) if captured fish were over 299 mm, and would have ranged from 5 to 16% (12% average) for northern pike over 449 mm, if the harvest occurred solely on this length category.

Winter access to Volkmar Lake was improved in late 1985 through the development of a snow machine trail from State-sponsored agricultural development lands northeast of Delta Junction. A slight increase in angler-days was observed in 1985 and 1986, however angler-days declined thereafter to levels observed before the winter access trail was improved. A sport fishing lodge and guiding operation has operated seasonally on Volkmar Lake since 1987. Increased access, possible changes of seasonality in the fishery, and initiation of a guiding operation did not result in substantially greater reported harvest than that observed prior to the development. Without direct estimates of sport harvest seasonality, methods, and composition, the causative effect of the current recreational fishery upon specific population composition categories is open to speculation.

Survival and recruitment of fully recruited northern pike were examined to see if there were corresponding trends between these statistics and abundance. Point estimates of survival decreased between 1986 and 1989, similar to decreases observed in abundance during the same time. However, variation in the estimation of survival is too great to suggest with statistical confidence that substantial changes in survival actually occurred for the sampling years reported. The upper limit of the 95% C.I. for these estimates barely exceeds 50% for two (1978-88, 1988-89) of the five time intervals, which is a concern. The point estimate of survival between 1989 and 1990 (Rate = 1.27) was an impossibility, due in part to large variation in the estimate. With 95% confidence, survival between 1989 and 1990 lies somewhere between 72 and 100%. The survival estimated between 1990 and 1991 (77%, SE = 13), while having a large confidence interval, may lend some encouragement regarding the potential for population increase, especially when coupled with the relative trend of increase in abundance noted for age 4 and younger cohorts.

Recruitment of age 5 fish did not significantly differ between 1985 and 1987, but a dramatic decline in recruitment (age 5 abundance) occurred between 1987 and 1988 (Figure 6). A significant decline again occurred between 1988 and 1989. Between 1989, and the years 1990 and 1991, the point estimate of recruitment of age 5 fish increased, paralleling increased abundance of northern pike. However variation in the point estimate of recruitment for 1990 and 1991 is too great to suggest a statistically significant increase. These recruitment failures parallel declines in population abundance, and are thought to be the primary reasons associated with the decline of overall abundance and composition shifts of northern pike in Volkmar Lake.

If change in the length composition of the population over time is driven primarily by recruitment, then declines in age 5 fish (about 520 mm; Figure 11) should result in proportionally fewer fish in the medium size category (450-749 mm) for the years 1988 and 1989. Abundance of fish in the medium size category does indeed plummet during this period, compared to other years. However, the proportion of medium size fish increased in 1988 and 1989, compared to other years, due primarily to fewer northern pike in the small category (comprised mainly of age 4 and younger fish). For the years 1988 and 1989, failures in cohort abundance extended over several young age classes (partial recruits - age 4 and younger) and first became apparent with age 5 recruits. This hypothesis is substantiated by continued recruitment failure of age 5 fish in the following years (1990 and 1991). Thus, the higher proportion of medium sized fish seen in 1988 and 1989 could have been due to even greater decreased proportions of smaller sized fish, relative to medium sized fish. The estimated abundance of age 4 and younger northern pike increased in the years 1990 and 1991, compared with 1988 and 1989. The relative absence of age 5 and younger northern pike is also reflected in the decrease of the RSD Stock category between 1987 and 1988-1989 periods (Figure 4).

Kipling and Frost (1970), in a long-term study of a lake population of northern pike, found that year class strength over a 19 year period (1943-1965) in the population studied (Windermere, England) varied up to five-fold. Year class strength was not significantly correlated with numbers of the parent stock or female spawner biomass, but was correlated with first year growth and optimum water temperature (degree days > 14 C) in the first year of life. Optimum water temperature was found to influence (for age 0+ fish) both growth and food availability (zooplankton). Kipling and Frost (1970) also found that high-density of northern pike 0+ cohorts results in increased within-cohort cannibalism. Size-dependent survival was inferred, in that northern pike progeny that grew well early in life were able to more successfully avoid being cannibalized both within and between cohorts. The authors found that the higher the percentage of optimally growing 0+ northern pike, the higher the cohort density in subsequent years. The authors related low cohort abundance in the period after the year of hatching to whatever factors slowed individual growth, and/or increased predation by other northern pike. The factors affecting cohort survival of northern pike studied by Kipling and Frost (1970) may apply to Volkmar Lake and other lakes studied in Alaska.

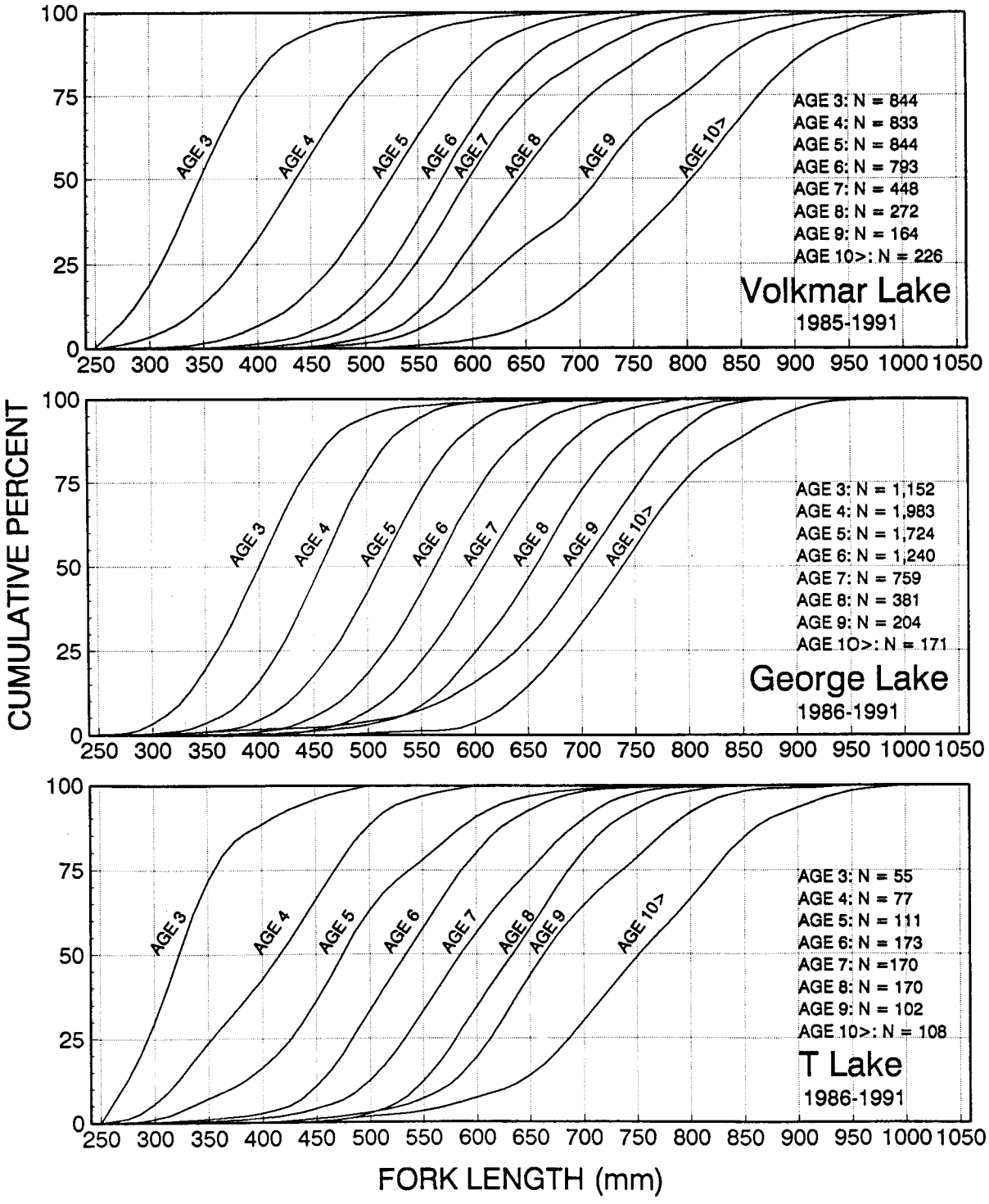

Figure 11. Cumulative length distribution frequencies of northern pike by age sampled in Volkmar, George, and T lakes, 1985-1991.

The sex composition of the population was not estimated in 1989, 1990, and 1991. However, when the length and age compositions of sampled northern pike for the years 1985 to 1991 are examined, female fish are generally found to be longer at age (Figure 12). Female cumulative proportion by length appears lower than males (Figure 13), indicating female northern pike attain a longer ultimate length through the combined effects of higher growth rates and/or increased longevity.

George Lake

Point estimates of population abundance of northern pike in George Lake increased between 1987 and 1988 and then decreased in 1989, however, variation about the estimates is so great that there is no statistical difference in abundance in these years (for lengths > 299 mm). In 1990, the population of northern pike > 299 mm (but not > 449 mm) significantly decreased in abundance from that in 1989. The 1991 estimate for both length groups does not significantly differ from the 1990 value. The estimate for 1990 is considered a minimum because of incomplete mixing during the mark-recapture experiment. To alleviate this problem in 1991, sampling effort (seine hauls) was allocated as uniformly as possible between all three lake areas during both the mark (Area 1: 38%; Area 2: 16%, and Area 3: 46%), and recapture events (Area 1: 40%; Area 2: 30%, and Area 3: 30%). These measures apparently promoted uniform capture probabilities and mixing of marked and unmarked fish. Population densities in George Lake have ranged from 6.3 to 14.0 northern pike over 299 mm per ha, and lie midway in range between that observed in Volkmar Lake (high densities) and T Lake (low densities).

The RSD proportions estimated for George Lake have remained relatively stable from 1986 through 1991. The proportions of stock fish in the period 1988 to 1991, although slightly declining from the period 1986 to 1987, still represent good recruitment. Few northern pike have been sampled in the preferred, memorable and trophy categories. Based upon growth modeled with the von Bertalanffy growth equation (Timmons and Pearse 1989), northern pike in George Lake have the capability to grow to sizes in these categories. Mean length-at-age of northern pike in George Lake (sexes combined) exceeds estimates for northern pike residing in Volkmar and T lakes through age 4, then becomes similar for older ages among all three lakes. The fact that few northern pike in the larger size categories are sampled in George Lake may be that they are inaccessible to the sampling gear (in deeper portions of the lake), or are not surviving to ages associated with larger size categories.

The sex composition of the population was not estimated in 1989, 1990, and 1991. However, when the length and age compositions of sampled northern pike for the years 1985 to 1991 are examined, female fish are generally found to be longer at age. Female cumulative proportion by length appears lower than males, indicating female northern pike attain a longer ultimate length through the combined effects of higher growth rates and/or increased longevity. There appears to be a lower cumulative proportion of fish (both sexes and combined) over approximately 450 mm in George Lake than in either Volkmar and T lakes, possibly due to proportionally fewer northern pike larger than that length in the George Lake population.

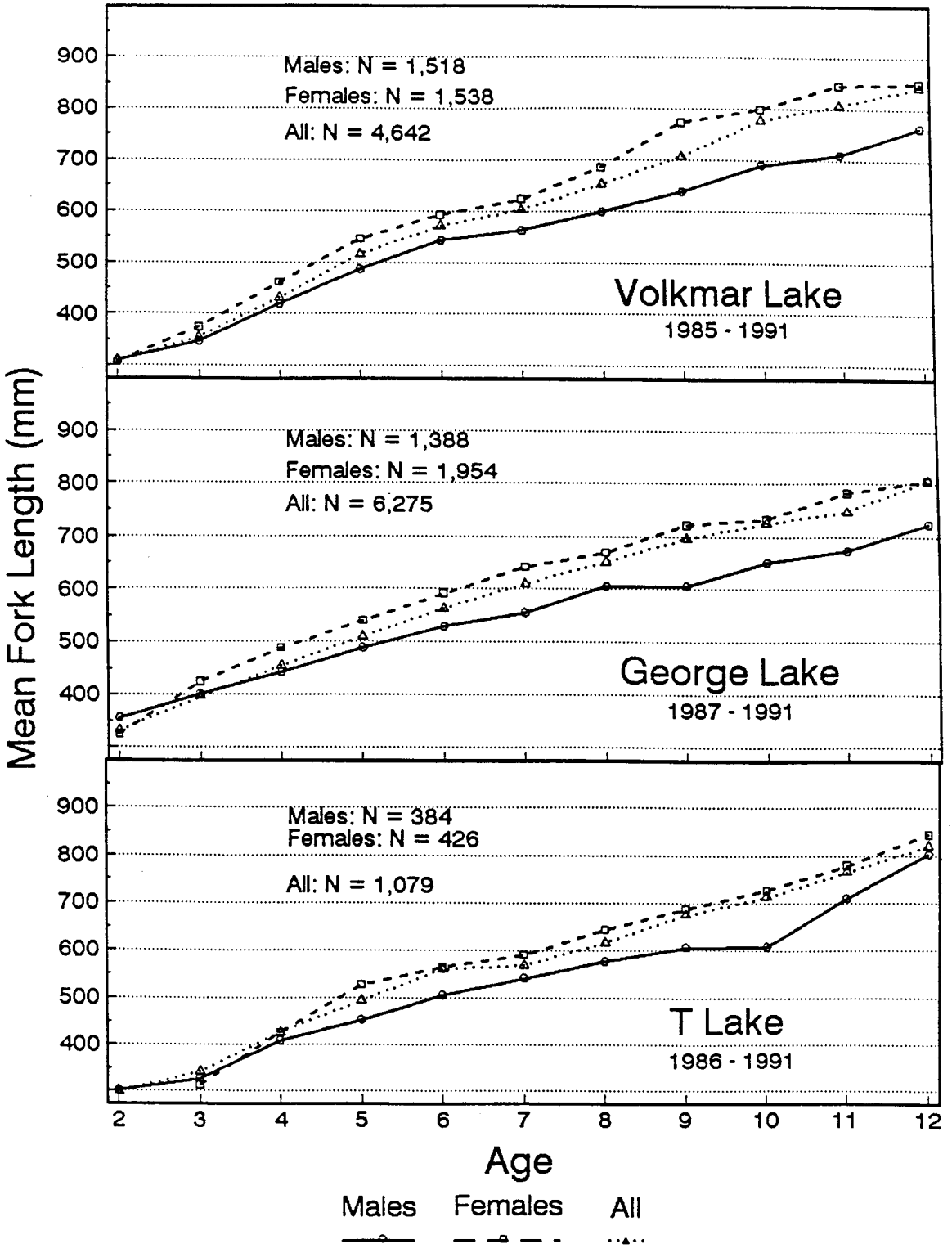

Figure 12. Estimated mean length-at-age of northern pike (> 299 mm FL) in Volkmar, George, and T lakes, 1985-1991.

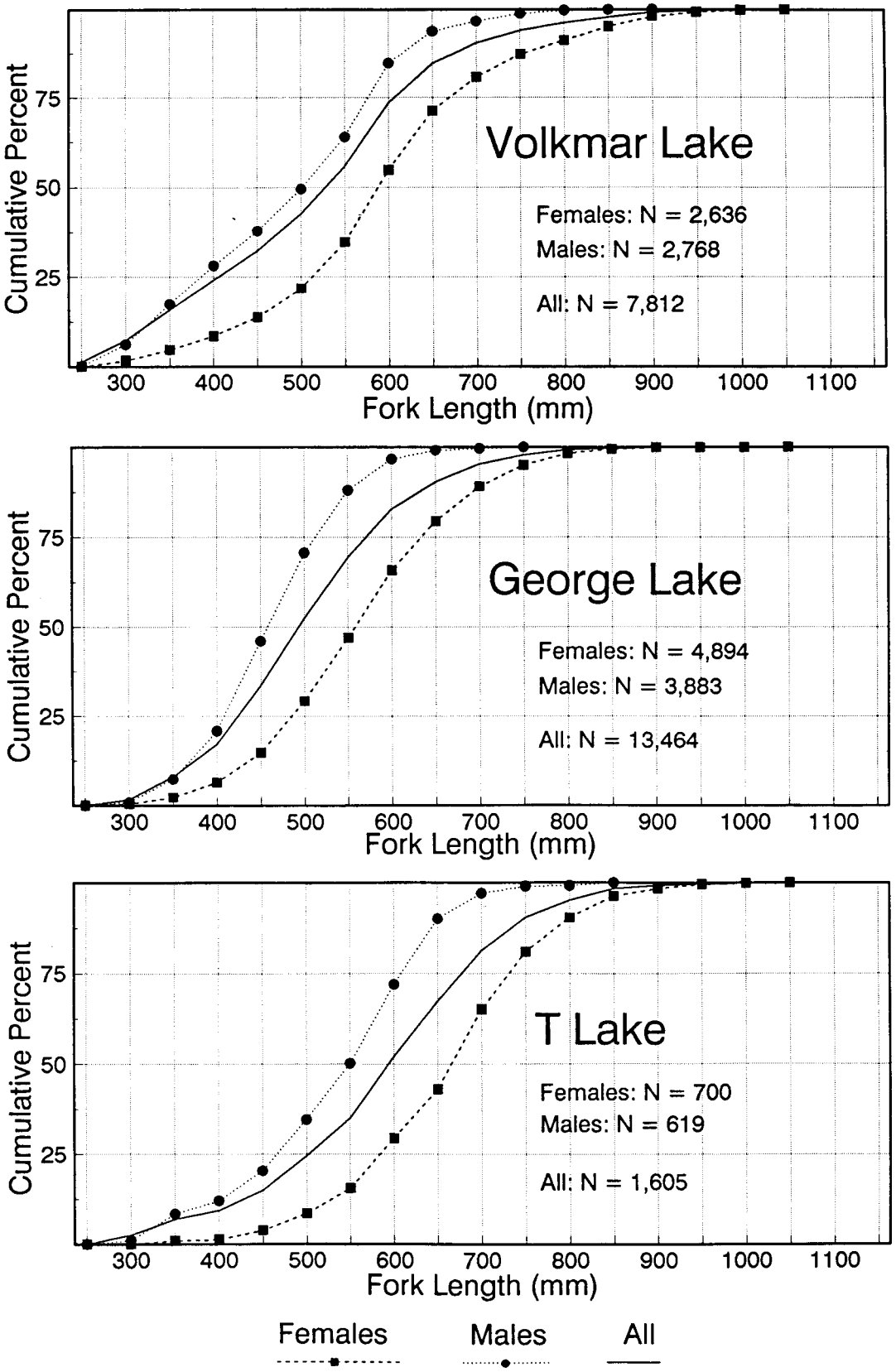

Figure 13. Cumulative length distribution frequencies of northern pike (all lengths) sampled in Volkmar, George, and T lakes, 1985-1991.

The most abundant cohort from 1987 to 1990 was age 4 fish. The majority of males mature at age 4. The majority of female northern pike in George Lake appear to recruit at ages 4 and 5. Age at full recruitment is likely sex dependent, and occasionally occurs across one or more age classes. This phenomenon appears common to lake populations of northern pike studied, although age at recruitment differs among lakes. Age at full recruitment is likely a function of growth rate, in that faster growing northern pike attain lengths associated with maturity at a younger age. However, the components of the age and length at maturity schedule were not tested.

The survival rate of northern pike in George Lake was low (35%, SE = 6) between 1989 and 1990, primarily due to the minimum abundance estimate for 1990 (11,567). Because of large variation in survival estimates for previous years, there are few statistical differences (determined from 95% confidence interval overlaps) in survival rates among years. The estimate of survival between 1990 and 1991 (93%, SE = 13) while statistically higher than the preceding period, is due in part to the minimum estimate generated in 1990. There is a significant decline in recruitment starting in 1991, that may be due to problems associated with the mark and recapture experiment. The estimate of recruitment in 1991 is unchanged from 1990 (Figure 8).

Recreational harvests of northern pike in George Lake since 1987 appear sustainable. Effort and harvest have both declined since 1987. Estimated exploitation rates of northern pike since 1987, if applied to fish over 299 mm, would have ranged from 3 to 13%, and if applied solely to northern pike over 499 mm, would have ranged from 7 to 26%. The current sport fish daily harvest regulation of one over 30 inches total length (720 mm FL), potentially affected 4.7% of the estimated fish population in George Lake during 1990 and 1991. Point estimates of recruitment in George Lake have exceeded sport harvest by at least 100% in all years estimated. Total mortality exceeded 50% only between 1989 and 1990, and that value (65%) is probably an overestimate.

T Lake

The population of northern pike in T Lake can generally be characterized as one of low population density, slow initial growth rates, low proportional recruitment, and probably little capacity to sustain recreational harvest compared to larger waterbodies such as Volkmar and George lakes. The estimated abundance and density of northern pike significantly declined in 1989. The estimates since 1989 are not statistically different (from 95% confidence interval overlaps). Density estimates of northern pike over 299 mm in T Lake (which range from 1.9 to 3.9 fish per ha) are at the low end among the three lakes studied.

Several indicators point to low rates of recruitment. The proportion of small northern pike from 1987 to 1991 (which ranged from 9 to 17%) is generally lower than that seen in Volkmar and George lakes. RSDs reflect, on average, lower proportions of fish in the stock category, and higher proportions of fish in the quality, preferred and memorable categories, than Volkmar and George lakes.

Male northern pike in T lake have generally been closely grouped by length within a 100 mm range. The frequency peaks increased in length through time probably due to growth. Female length frequencies generally peaked at a longer length within a given year, and also reflect growth over time. Northern pike (sexes combined) length frequencies indicated peaks at longer lengths than in Volkmar and George lakes, and reflect low recruitment.

The sex composition of the population was not estimated in 1989, 1990, and 1991. However, when the length and age compositions of sampled northern pike for the years 1985 to 1991 are examined, female fish are generally found to be longer at age. Female cumulative proportion by length appears lower than males, indicating female northern pike attain a longer ultimate length through the combined effects of higher growth rates and/or increased longevity.

Estimated cohort dominance of T Lake northern pike has shown yearly variations since 1986. Age 6 northern pike dominated in 1987 and 1988, while age 8 cohorts dominated in 1986, 1989, 1990, and 1991. The sample sizes that drove this analysis, and differences between estimated abundance were statistically insignificant. Therefore, age 6 was chosen as the age at full recruitment. As in the other lakes studied, male northern pike in T Lake probably drive the age of cohort abundance and initial full recruitment. Age 6 and 7 males, and age 7 and 8 females were most abundant of fish sampled.

The annual survival and recruitment of fully-recruited northern pike in T Lake, estimated since 1986, indicates limited variability in the data. Between 1986 and 1987, survival was overestimated (104%) for unknown reasons. Errors in properly apportioning the abundance estimates for grouped-cohorts due to ageing error, or normal variability in the estimates, are possible sources. Clark (1988), using tagged-fish capture histories, estimated survival between 1986 and 1987 at 85.6%, a more realistic figure. Total annual survival estimates for the years 1987-88 (65%), 1988-1989 (58%), 1989-1990 (84%), and 1990-1991 (79%) are statistically similar and collectively reflect tentatively acceptable levels of total annual mortality less than 50%.

Recruitment from 1986 to 1991 in T Lake initially increased and then significantly decreased. The 1989 estimate (36, SE = 11) for the age 6 cohort is the lowest since inception of the study at T Lake. The average proportion of age 6 northern pike (18%), is similar to that for fully recruited age 5 Volkmar Lake fish (19%), but is below that estimated for age 4 George Lake northern pike (29%). However, recruitment is numerically low (avg. = 80 fish), when potential sport harvest is considered. Clark (1988), estimated a minimum sport harvest of 43 northern pike (10.7% exploitation rate) between 1986 and 1987, and qualified that harvest as apparently sustainable. Mills (pers. com.[1]), estimated a harvest of 60 northern pike in 1989, which equals an exploitation rate of between 20 and 22%, depending on the length categories affected. While this estimate is unqualified (no SE), and although T Lake harvest typically is not reported by Mills, it does point out the potential for the harvest from a few anglers (12 catching their daily bag limit of five fish less than 720 mm) to exceed the yearly recruitment and to exceed the

[1] Mills, M. J. 1991. Personal Communication. ADFG, 333 Raspberry Road, Anchorage, Alaska 99518-1599.

recommended limit for exploitation (15%) in this small interior Alaskan waterbody.

Conclusions

The Alaska Department of Fish and Game (ADFG) has been most successful in capturing northern pike which are concentrated in lakes during spring spawning. There appears to be a variable time window in each lake during which sufficient within-season recaptures of desired sizes of marked fish are obtainable. Such a window may be opened or closed by environmentally-influenced biological factors which are beyond our control, and dictate the onset, duration, and completion of spawning. These factors thus influence fish availability to the sampling gear, as post spawning northern pike appear less susceptible to the gear (sampling success with seines typically declines during the mark-recapture process). In years when the time window and catchability allowed adequate marking, mixing and recapture probabilities, estimates of abundance and composition have been developed (Appendix A). Sometimes variability about the estimate has precluded our ability to detect statistically significant differences in fluctuations of abundance and composition. To decrease variability, sampling rates (for fish > 299 mm) could be increased within the existing time window (to satisfy the need for sample size while still allowing for adequate mixing), or population and composition estimates could be based not on sizes of northern pike released over 299 mm, but rather upon cumulative cohort abundance beyond the age at full recruitment for the waterbody in question.

In all lakes studied, research efforts to date have focused on estimating the abundance and composition of northern pike over 299 mm. The selection of this size minimum occurred early in the program, when low capture rates (with gill nets, seine and traps) of northern pike shorter than this length were observed, and sampling fish of this length and larger assured capture of fully recruited northern pike. Mark-recapture experiments for northern pike over 299 mm have not always been successful. For example, in 1985 in Volkmar Lake, and in 1986 in T Lake, no recaptures of marked fish less than 450 mm occurred, which necessitated an estimate for only fish of that length and greater (Clark and Gregory 1988, Clark 1988).

There are few published studies on northern pike relating total annual mortality, and its components (natural and fishing), to surplus production, recruitment, population composition, and ranges of sustainable recreational harvest in northern pike populations. We have yet to develop estimates of surplus production. Until estimates of surplus production, and/or population composition guidelines are developed, it is recommended that total annual mortality, and fishing mortality, for fully recruited northern pike in lakes studied not exceed 50% and 15%, respectively. A limit of 50% total mortality would allow 10% of northern pike to survive at least three years, and at least 1% to survive at least seven years, beyond the age at full recruitment.

The minimum total mortality estimated for Volkmar Lake was 29%; for George Lake, 20%; and for T Lake, 15%. Fishing mortality can replace natural mortality, and therefore the two are not necessarily additive. Using the worst case scenario, natural mortality probably did not exceed 30% from 1985

to 1990. The current recommendations for conservative management of northern pike are to limit fishing mortality of fully recruited (to the spawning population) fish to 15% or the year's recruitment, whichever is lower. These guidelines should provide an adequate margin to sustain yield in years of successful recruitment. In years of poor recruitment, even a lack of sport fishery exploitation may not prevent dramatic declines in population abundance and marked changes in composition.

If Alaskan northern pike populations are at the whim of variable recruitment, as appears in Volkmar Lake, then the development of regulations to create and protect balanced northern pike populations may temper potential recruitment variability, and may require choosing composition goals as a management objective over maximizing surplus production.

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APPENDIX A

Appendix A. Sampling dates and abundance estimate types for Volkmar, George, and T lakes, 1985-1991.

		Dates	Type Estimate	Comments[a]
Volkmar Lake:				
1985	Mark Event	5/31-6/6	Stratified Petersen (> 449 mm FL)	No recaps < 450 mm.
	Recapture Event	6/17-6/19	(1) 450 - 699 mm	Gear selectivity for large
	11-day hiatus		(2) > 699 mm	fish with gill nets noted.
1986	Mark Event	6/3-6/6	Stratified Petersen	Gear selectivity occurred for
	Recapture Event	6/16-6/19	(1) < 450 mm	large fish with gill nets
	10-day hiatus		(2) 450-749 mm	(also seines/traps used;
			(3) > 750 mm	not selective).
1987	Mark Event	5/19-5/25	Stratified Petersen	Beach seine used
	Recapture Event	5/27-5/29	(1) 300-549 mm (Darroch)	(some gillnetting).
	2-day hiatus		(2) 550-645 mm (Darroch)	Sampling gears selective
			(3) > 650 mm (Petersen)	for large fish.
				Large fish (3) didn't mix.
1988	Mark Event 1988	5/23-5/31	Two-Season Stratified Petersen	Seines used from this year on.
	Recapture Event	1989	(1) 300-525 mm (Robson/Flick)	Insufficient fish captured to
			(2) 526-675 mm (Petersen)	do a within-season estimate.
			(3) > 676 mm (Petersen)	
1989	Mark Event 1989	5/19-5/29	Two-Season Petersen	Insufficient captures during 1989
	Recapture Event	1990	(Robson/Flick)	for within-season estimates.
				Case IV B for composition estimates.
1990	Mark Event	5/16-5/19	Unstratified Petersen	Case IV B for composition estimates.
	Recapture Event	5/22-5/24		
	3-day hiatus			
1991	Mark Event	5/20-5/25	Petersen	Case IV B for composition estimates.
	Recapture Event	5/28-5/30		
	3-day hiatus			
"T" Lake:				
1986	Mark Event	5/30-6/1	Stratified Petersen (> 450 mm FL)	No recaps < 450 mm.
	Recapture Event	6/11-6/12	(1) 450-749	Gill nets size selective
	10 day hiatus		(2) 750 —>	for large fish.
				Mixing okay.

-continued-

Appendix A. (Page 2 of 2).

	Dates		Type Estimate	Comments
1987	Mark Event	5/27-5/29	Petersen	Mix okay; no length bias
	Recapture Event	6/1-6/3	(1) 300-449 mm	(stratified to simplify
	3-day hiatus		(2) 450-745 mm	comparison between years only).
			(3) 750 —> mm	
1988	Mark Event	5/18-5/21	Petersen	Mixing sufficient, no size bias
	Recapture Event	5/23-5/28		detected.
	2-day hiatus			
1989	Mark Event	5/18-5/26	2 season Petersen	1990 Recap event.
	Recapture Event	1990	(Robson/Flick)	Insufficient captures
				to do 1988 estimate.
1990	Mark Event	5/18	Petersen	Case II
	Recapture Event	5/20-5/21		Composition estimate.
	1-day hiatus			
1991	Mark Event	5/20-5/21	Stratified Petersen	Composition weighted by area abundance
	Recapture Event	5/24-5/25	By Area	and summed across area strata
George Lake:				
1987	Mark Event	6/2-6/9	Darroch	Unequal mixing/mark probabilities.
	Recapture Event	6/23-6/29		
	14-day hiatus			5 strata for composition estimate
				using 2nd event data.
1988	Mark Event	5/24-5/28	Darroch	Unequal mixing/mark probabilities.
	Recapture Event	6/1-6/4		Size selectivity during 1st event =
	3-day hiatus			2nd event for composition.
1989	Mark Event	5/31-6/5	Petersen	Case II composition estimate.
	Recapture Event	6/9-6/12		
	4-day hiatus			
1990	Mark Event	5/25-5/29	Minimum Petersen	Case II composition estimate.
	Recapture Event	6/1-6/3	(stratified by area)	
	2-day hiatus		(1) area 1 & 3	Fish failed to mix between lake
			(2) area 2	area.
1991	Mark Event	5/24-5/26	Petersen	Case I for composition estimates.
	Recapture Event	5/30-6/05		
	3-day hiatus			

[a] See Appendix C for definition of Cases (e.g. Case IV B).

APPENDIX B

Appendix B. Fin clips and tags assigned to northern pike in Volkmar, George, and T lakes 1983-1991.

Year	Tag Series	Color[a]	Fin Clips[b]	Comments
George Lake				
<1983	Jaw Tags		None	
1983	16197 - 16206	Red	None	
1984	16221 - 16305	Red	None	
1985	No Sampling			
1986	3000, 4000 series	Yellow	004	Coded LV in original data.
	17000 series	Red		
1987	20000, 30000 series	White		
	17715		008	Most tagged fish given 008; when ran out of tags, gave 002; a few tagged fish given 002.
	17836 - 17999	Red	002	
1988	62000 - 62356	White	064	
	96000 - 97999	Green		
1989	20300 - 20999	Green	Option 5 = 2	Left opercle punch
	23000 - 23599	Green	Same	
	24000 - 24999	Green	Same	
1990	55000 - 55999	Blue	Option 5 = 1	Right opercle punch
	56000 - 57179	Blue	Same	
1991	54001 - 54998	Blue	Option 5 = 4	Dorsal fin clip
	57200 - 57999	Blue	Same	
	58000 - 58597	Blue	Same	
Volkmar Lake				
1983	16189 - 16196	Red	None	
	174 - 214	Blue		
1984	16207 - 16347	Red	None	
1985	16431 - 17568	Red	None	
1986	3000, 4000 series	Yellow	016, 032	032 = fish > 499 mm;
	16000, 17000 series	Red	Many odd combos	mostly untagged fish during marking run; mostly tagged fish during recap run.
	20400 - 20454	White		016 = fish < 500 mm; most tagged.
				Odd 16000, 17000 series tags from previous years.

-continued-

Appendix B. (Page 2 of 2).

Year	Tag Series	Color[a]	Fin Clips[b]	Comments
1987	25000 - 26037	White	008	
			Many odd combos	
1988	98000 - 98355	Green	064	
			Many odd combos	
1989	21000 - 21383	Green	Option 5 = 2	Left opercle punch
1990	50000 - 50516	Blue	Option 5 = 1	Right opercle punch
1991	50517 - 50999	Blue	Option 5 = 4	Dorsal fin clip
	51000 - 51307	Blue	Same	
T Lake				
1986	3247 - 3618	Yellow	002	002 = accidental
			004	wrong clip; 004 =
			032	Mark Run; 032 =
				Recap Run.
1987	17569 - 17834	Red	008	
1988	99000 - 99139	Green	064	
1989	20000 - 20017	Green	Option 5 = 2	Left opercle punch
	20050 - 20058	Green	Same	
1990	59000 - 59055	Blue	Option 5 = 1	Right opercle punch
	59100 - 59126	Blue	Same	
1991	59250 - 59299	Blue	Option 5 = 4	Dorsal fin clip
	59344,59346-7	Blue	Same	
	59349	Blue	Same*	

[a] Color Codes: 01 = Not Checked, 02 = Yellow, 03 = Green, 04 = White, 05 = Red, 06 = Blue.

[b] Fin Clip Codes: 001 = Adipose, 002 = R. Pelvic (Ventral), 004 = L. Pelvic (Ventral), 008 = R. Pectoral, 016 = L. Pectoral, 032 = U. Caudal, 064 = L. Caudal, Option 5 = 2 = Left opercle punch, Option 5 = 1 = Right opercle punch.

APPENDIX C

Appendix C. Methodologies for alleviating bias due to gear selectivity by means of statistical inference.

Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]	
Fail to reject H_0	Fail to reject H_0
Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]	
Fail to reject H_0	Reject H_0
Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event	
Case III[e]	
Reject H_0	Fail to reject H_0
Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]	
Reject H_0	Reject H_0
Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first K-S (Kolmogorov-Smirnov) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Also calculate a single abundance estimate without stratification.

a. If stratified and unstratified estimates are dissimilar, discard unstratified estimate and use lengths and ages from second event and adjust these estimates for differential capture probabilities.

b. If stratified and unstratified estimates are similar, discard estimate with largest variance. Use lengths and ages from first sampling event to directly estimate size and age compositions.